THE UNITED STATES DISTRICT COURT
FOR THE EASTERN DISTRICT OF TEXAS

LUX, INC.,	)	
	)	
Plaintiff,	)	
	)	Civil Action No. 07-CV-520
v.	)	
	)	
BRIGHTBLUE CORPORATION,	)	**JURY TRIAL DEMANDED**
	)	
	)	
Defendant.	)	

PLAINTIFF'S OPENING CLAIM CONSTRUCTION BRIEF

I. INTRODUCTION

It is an established tenet of patent law that claims define the invention and limitations from the specification should not be imported into the claims. *Phillips v. AWH Corp.*, 415 F.3d 1303, 1323 (Fed. Cir. 2005) (en banc). Defendant has repeatedly violated this principle by seeking constructions that import limitations from illustrative embodiments of the specification into the claims. Such constructions are inconsistent with the claims' plain language and do not reflect the careful balance of using embodiments disclosed in the specification to enable one skilled in the art to practice the invention without confining the claims to those embodiments. *See id.* at 1323. Specifically, BrightBlue's proposed construction of "inclusion" is a transparent attempt to severely restrict the scope of the claims by hanging on to a few sentences in the specification. Such a construction, which does not reflect the ordinary and customary meaning of the claim terms, must be rejected.

LUX, Inc.'s ("LUX") constructions, on the other hand, do not import extraneous limitations and are consistent with the claims' plain language as well as being supported by the specification. LUX's constructions reflect the balance of interpreting claims in light of the specification, while avoiding importing limitations from the specification.

II. BACKGROUND

U.S. Patent No. 5,075,742 (the "'742 patent") (attached as Exhibit 1), entitled "Semiconductor Structure for Optoelectronic Components with Inclusions," is directed to a novel use of "inclusions" to improve the operation of certain types of semiconductor devices.

An application of the '742 patent relates to light emitting diodes, or "LEDs." LEDs are semiconductor devices that convert electric current into light and are commonly found in traffic signal lights and consumer electronics such as cellular phones and portable computers for display lighting. Generally speaking, an LED consists of layers of different semiconductor material that are grown on a base material, or a "substrate." A common design for LEDs includes an active layer of semiconductor material formed between two oppositely doped layers, one being "p-type" and the other being "n-type." The "p-type" layer has positive charge carriers, called holes, and the "n-type" layer has negative charge carriers, called electrons. During operation, a current is applied across electrical contacts to the doped layers, which causes negatively charged electrons and positively charged holes to move from the doped layers into the active layer. The electrons and holes meet and recombine to generate light. The light is emitted in all directions from the active layer and escapes from the surfaces of the LED.

During the manufacturing process of LEDs, when a layer of one type of semiconductor material is grown on a base or substrate of a different material, cracks or so-called "dislocations" can result. For example, when gallium arsenide (GaAs) layers are grown on a silicon (Si) substrate, or gallium nitride (GaN) layers are grown on a sapphire substrate, the atoms in the grown crystalline semiconductor layers do not exactly line up with those in the substrate so numerous cracks or dislocations can form in the layers. These cracks or dislocations can be so numerous that they can prevent light from being generated altogether (or at least interfere with device performance). These dislocations affect light output by trapping electrons and holes in sites that do not emit light. Such dislocations are undesired in semiconductor light emitting devices.

The inventors of the '742 patent conceived of a novel device design where the problem of such dislocations could be by-passed by adding "inclusions" during the growth of the active layer of an LED or laser diode. The inclusions serve a unique purpose for improving the optical properties of semiconductor devices that suffer from the dislocation problem mentioned above, *i.e.*, where the device layers are formed on a substrate of different material. The "inclusions" are formed from semiconductor material having a lower "forbidden band gap" (also called "bandgap") than the surrounding material such that electrons and holes are attracted to and move to the inclusions, are trapped there, and recombine to lead to the emission of light. Importantly, the inclusions trap electrons and holes away from dislocations, limiting their negative effects.

III. CLAIM CONSTRUCTION LEGAL STANDARDS

Words of a claim "are generally given their ordinary and customary meaning." *Phillips*, 415 F.3d at 1312 (quoting *Vitronics Corp. v. Conceptronic, Inc.*, 90 F.3d 1576, 1582 (Fed. Cir. 1996)). In some cases, "the ordinary meaning of claim language as understood by a person of skill in the art may be readily apparent even to lay judges, and claim construction in such cases involves little more than the application of the widely accepted meaning of commonly understood words." *Phillips*, 415 F.3d at 1314.

In most cases, ascertaining the ordinary and customary meaning of the claims requires the court to consider "those sources available to the public that show what a person of skill in the art would have understood disputed claim language to mean." *Phillips*, 415 F.3d at 1314 (quoting *Innova/Pure Water, Inc. v. Safari Water Filtration Systems, Inc*, 381 F.3d 1111, 1116 (Fed. Cir. 2004)). Such sources include the intrinsic record, *viz.*, the claims, the specification, and prosecution history. *Id.* As stated in *Phillips*, "the person of ordinary skill in the art is deemed to read the claim term not only in the context of the particular claim in which the disputed term appears, but in the context of the entire patent, including the specification." 415 F.3d at 1313.

Although the specification is highly relevant in determining the meaning of a claim term, courts must be careful to avoid "the danger of reading limitations from the specification into the claim." *Phillips*, 415 F.3d at 1323. In *Phillips*, the Federal Circuit acknowledged that the distinction between reading claims in light of the specification and importing limitations from the specification into the claim can be difficult and stated that "although the specification often describes very specific embodiments of the invention, we have repeatedly warned against confining the claims to those embodiments." 415 F.3d at 1323. To avoid importing limitations from the specification into the claims, the Federal Circuit noted that it is important to remember that the purpose of the specification is to teach and enable those skilled in the art to make and use the invention and to provide a best mode for doing so, not to necessarily restrict the invention to specific examples provided in the specification. *Id.* According to the Federal Circuit, the "manner in which the patentee uses a term within the specification and claims usually will make the distinction apparent." *Id.*

Finally, although intrinsic evidence is most informative in determining the claims' customary and ordinary meaning, a court may use extrinsic evidence, which "consists of all evidence external to the patent and prosecution history, including expert and inventor testimony, dictionaries, and learned treatises." *Phillips*, 415 F.3d at 1317 (quoting *Markman v. Westview Instruments, Inc.*, 52 F.3d 967, 980 (Fed. Cir. 1995) (en banc)).

IV. CONSTRUCTION OF "INCLUSION"

Claim Language	LUX's Proposed Construction	BrightBlue's Proposed Construction
inclusion/ three-dimensional inclusions	An "inclusion" means "a crystal or a fragment of a crystal found within another crystal." Given this construction of "inclusion," the phrase "three-dimensional inclusions" does not require further construction by the Court.	BrightBlue proposes to construe "three-dimensional inclusion" as "islands grown using three-dimensional nucleation and then buried by a different material."

LUX contends that the term "inclusion" should be construed according to the meaning that it has in its ordinary use in the field: a crystal or fragment of a crystal found within another crystal. BrightBlue, in contrast, contends that the term should be construed to include two limitations: (1) shaped like islands and (2) grown only by a three-dimensional nucleation process. The intrinsic record does not require these limitations, and importing them from the specification into the claims is thus improper.

The specification supports LUX's construction. First, the inclusions clearly comprise semiconductor material surrounded by other semiconductor material. *See* '742 patent, claim 1 (inclusions are made of "semiconductor material"); 5:37-37 (in a preferred embodiment, the InAs inclusions are "buried inside the active layer 4a"). Second, inclusions comprise different material than their surroundings. This is because "[t]he main object of this invention is to reduce the influence of dislocations," *id.* at 2:5960, and thus inclusions clearly "ensure a function of traps for the carriers, thereby avoiding diffusion of the latter towards the core of the dislocations and the associated nonradiative centers." *Id.* at 3:5-8. To accomplish this function, inclusions must differ from the material that surrounds them; in particular, they must have a lower forbidden band gap. *See id.* at 4:55-66. Third, inclusions—like their surroundings—are crystalline in nature, as they are formed "during the semiconductor crystal growth." *See* '742 File

History (Exhibit 2 at 48); *see also* ’742 patent, 5:37-38 (“Constrained within the GaAs lattice, the inclusions do not however contain any dislocation”).

LUX’s construction, as supported by the specification, is consistent with the plain meaning of the term and follows from its consistent use in a number of contexts, including crystallography and metallurgy. In general, an inclusion is some material that is encased in a larger host and differs in composition from its surroundings. *See, e.g.*, DICTIONARY OF MECHANICAL ENGINEERING 203 (4th ed. 1996) (Exhibit 4) (defining an inclusion as “[a] feature in a material . . . not identical to the material matrix”); MCGRAW-HILL DICTIONARY OF SCIENTIFIC AND TECHNICAL TERMS 947 (4th ed. 1989) (Exhibit 5) (in the metallurgical context, an inclusion is “[a]n impure particle . . . trapped in molten metal during solidification”). Thus, LUX’s construction of an inclusion as a crystal or part thereof contained within another crystal comports with the ordinary meaning. *See Mangosoft, Inc. v. Oracle Corp.*, 525 F.3d 1327, 1333 (Fed. Cir. 2008) (finding “nothing improper” about referencing a technical definition “when considered in the context of and not divorced from the intrinsic evidence”).

BrightBlue’s construction, on the other hand, seeks to add additional limitations to this plain meaning that are unsupported by the intrinsic record. Nothing in the specification or file history requires that inclusions have a particular shape or be made in any particular way.

First, the specification is clear that the growth method disclosed in a preferred embodiment is not the only one which may be used to create an inclusion: It is possible to apply the invention within the framework of *other growth techniques* for which a transition to a three-dimensional growth mode has been observed. The fabrication of a GaAs laser structure on Si with InAs inclusions is, *for instance*, also possible in vapor phase epitaxy from organometallic compounds. ’742 patent, 6:36-41. Claim 1 does limit the scope of the patent to devices where the inclusions are formed “during growth,” but it does not specify the particular growth method.

Second, the intrinsic record does not support BrightBlue’s proposed limitation on the shape of the inclusions that are to be inserted into the device. First, the text of the claim clearly indicates only that the inclusions are “three-dimensional,” without further restrictions on their shape. If the inventors intended to limit the shape of inclusions to an "island" shape, they surely could have elected to do so, as the term does appear when discussing one embodiment of the invention in the specification. *See, e.g.*, *id.* at 5:24 ("Islands 8 of indium arsenide InAs form at the surface."). However, it is improper here to import a limitation from the specification when the claim does not indicate any such limitation should be so imported. In fact, nothing in the patent indicates that the inventors intended to limit the scope of the invention to its preferred embodiments, and BrightBlue's proposed construction therefore is an impermissible attempt to limit the claims.

V. CONCLUSION

For the foregoing reasons, LUX respectfully requests that the Court adopt LUX's proposed constructions, which find proper support in the intrinsic record, and reject BrightBlue's proposed constructions.

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DEFENDANT'S RESPONSIVE CLAIM CONSTRUCTION BRIEF

I. INTRODUCTION

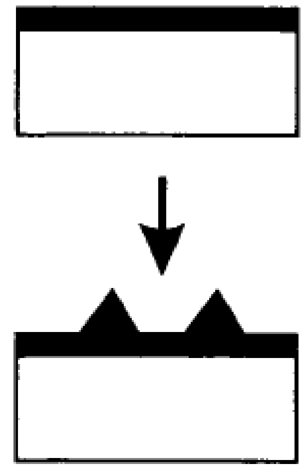
One hundred and thirty years ago, the Supreme Court articulated the principle that should guide this Court in construing disputed claim terms: "in case of doubt or ambiguity it is proper in all cases to refer back to the descriptive portions of the specification to aid in solving the doubt or in ascertaining the true intent and meaning of the language employed in the claims." *Bates v. Coe*, 98 U.S. 31, 38 (1878). That principle remains the law today. The Federal Circuit has repeatedly emphasized that the specification "is always highly relevant to the claim construction analysis. Usually, it is dispositive; it is the single best guide to the meaning of a disputed term." *Phillips v. AWH Corp.*, 415 F.3d 1303, 1315 (Fed. Cir. 2005) (en banc) (quoting *Vitronics Corp. v. Conceptronic, Inc.*, 90 F.3d 1576, 1582 (Fed. Cir. 1996)). The specification provides the context that is essential to the task of claim construction. *Id.* at 1313 ("the person of ordinary skill in the art is deemed to read the claim term not only in the context of the particular claim in which the disputed term appears, but in the context of the entire patent, including the specification"). BrightBlue's proposed constructions follow this approach, looking to the specification to help construe the language of the claims.

II. FACTUAL BACKGROUND

A. A variety of semiconductor growth techniques and growth modes were well-known in the art.

Semiconductor growth techniques can be used to make a variety of optoelectronic devices. Some optoelectronic devices are light-emitting (*e.g.*, lasers and light-emitting diodes) and some are light-absorbing (*e.g.*, detectors). The semiconductor layers of an optoelectronic device can be grown using a variety of techniques, all of which involve depositing a thin layer of semiconductor material by a process called "epitaxy." One common growth technique, used in the preferred embodiment of the patent, is called Molecular Beam Epitaxy (or "MBE"). In MBE, source materials are heated to produce an evaporated beam of particles in a vacuum chamber and then directed to the substrate, where they slowly form the epitaxial layer.

Using these growth techniques, a layer will usually grow two-dimensionally. That is, the layer will thicken as it grows, and the top surface will remain flat. But it has been known since 1937 that when certain semiconductor materials are grown on top of different materials, the material may grow three-dimensionally, forming islands that increase in size. This process is called three-dimensional nucleation. In one such growth process, called Stranski-Krastanov (or "SK") growth, the semiconductor first grows in a thin layer but, after a certain thickness, transitions to a mode in which it grows three-dimensional islands. The reason for this transition is the strain caused by the different materials being in contact. The SK growth mode is illustrated in the figure to the right, and is the growth mode disclosed in the patent.



SK

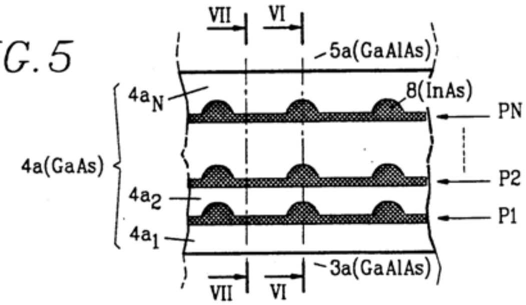
B. The '742 patent uses three-dimensional nucleation to confine charge carriers.

Gerard and Weisbuch's '742 patent discloses a multi-layer semiconductor structure in which "one of the layers comprises three-dimensional inclusions in a semiconductor material." (2:65-68.) These inclusions have a lower bandgap than the surrounding semiconductor material, making them the sites for radiative recombination of injected electrons and holes. (2:68-3:10.) According to the Summary of the Invention, the "inclusions are inserted during growth, by using the three-dimensional nucleation mode observed during the epitaxy of III-V materials that are highly mismatched with regard to the substrate used." (3:11-14.) That is, after "interrupting at least once" the growth of the layer, one "deposit[s] a thin layer of the semiconductor material having a narrower forbidden band than the forbidden band of the material of [the] layer," which constitutes the three-dimensional inclusions after it transitions to a three-dimensional growth mode and is then buried by further deposition of the layer material. (3:14-24.) The three-dimensional inclusions are "traps for the carriers." (3:5-6.)

In the preferred embodiment, three-dimensional growth occurs for InAs grown on GaAs using molecular beam epitaxy. (5:4-24.) Owing to the growth conditions, islands of InAs form on the surface of the GaAs sub-layer and are then buried by another sub-layer of GaAs. (5:24-

38.) The growth mode that the ’742 patent describes is SK growth, and it is illustrated in Figure 5 of the patent. Growth techniques besides molecular beam epitaxy can also be used, so long as they have a transition to a three-dimensional growth mode (vapor phase epitaxy is an example). (5:4-7; 6:36-38.)

FIG. 5



III. “THREE-DIMENSIONAL INCLUSIONS” ARE ISLANDS GROWN USING THREE-DIMENSIONAL NUCLEATION AND THEN BURIED BY A DIFFERENT MATERIAL.

Claim 1 requires that every sub-layer have “three-dimensional inclusions.” The specification placed great emphasis on “three-dimensional” growth, so it would be error to construe “inclusion” by itself. Critically, in the ’742 patent, “three-dimensional” is an adjective that does not describe the *shape* of the inclusions, but rather the *method* of growing them. The dictionary definition of “three-dimensional” is “of, relating to, having, or existing in three dimensions.” AMERICAN HERITAGE DICTIONARY 1801 (4th ed. 2006) (Exhibit 5). In the context of the patent claims, the inclusions relate to three dimensions in a particular way: the growth mode.

A. The invention is limited to “growth techniques for which a transition to a three-dimensional growth mode has been observed.”

“Three-dimensional growth,” also called “three-dimensional nucleation” in the art and in the ’742 patent, is fundamental to the invention disclosed and claimed in the patent. The “Summary of the Invention” states: “The inclusions are inserted during growth, by using the three-dimensional nucleation mode . . . .” (3:11-12.) Importantly, this is a “Summary of *the* Invention,” not a “Description of the Preferred Embodiments.” (Compare 2:64 and 3:54-55.) It is a declaration that “inclusions *are* inserted during growth, by using the three-dimensional nucleation mode,” not that they “may be” or “can be” formed this way. The specification, on this point, is dispositive. *See Vitronics*, 90 F.3d at 1582; *Honeywell Int'l, Inc. v. ITT Indus., Inc.*, 452 F.3d 1312, 1317-19 (Fed. Cir. 2006) (construing the apparently broader claim term “fuel injection system component" to mean "fuel filter," where a fuel filter was the only embodiment disclosed in the specification and was described as "the present invention").

The specification throughout confirms that a "three-dimensional inclusion" is something formed using three-dimensional nucleation. Shown in Figures 5, 8, 9, and 10 are the islands of indium arsenide that are characteristic of three-dimensional nucleation. These figures are key. They depict the formation of active layer 4a, and it is "the formation step of the active layer 4a" that distinguishes fabrication of a device "embodying the invention" from one "of the same type according to the prior art." (5:1-5.)

To be sure, some portions of the specification discuss a particular, preferred embodiment of the invention. So, for example, while the preferred embodiment is fabricated using MBE, the invention could also be made using other growth techniques such as vapor phase epitaxy. (5:4-7.) Indeed, according to the specification:

> It is possible to apply the invention within the framework of other growth techniques from which a transition to a three-dimensional growth mode has been observed. The fabrication of a GaAs laser structure on Si with InAs inclusions is, for instance, also possible in vapor phase epitaxy from organometallic compounds. (6:37-42.)

There are two important points about this quotation. First, the reference to "other growth techniques" is designed to expand beyond molecular beam epitaxy, to include for example "vapor phase epitaxy." Vapor phase epitaxy is another InAs growth technique that has a three-dimensional growth mode, and there exist others as well. Second, the quoted language specifies that "the invention" applies "within the framework of"—which means its outer bounds are set by—"growth techniques from which a transition to a three-dimensional growth mode has been observed." According to the specification, in short, the invention requires "a three-dimensional growth mode," or three-dimensional nucleation. *See Ormco Corp. v. Align Tech., Inc.*, 498 F.3d 1307, 1316 (Fed. Cir. 2007) ("Although their claim language does not expressly recite automatic control of the finish tooth positioning, that is what they mean, and that is all that the specification describes; the specification does not support operator positioning.").

LUX recognizes that the quoted language is fundamental, citing it as an aid in construing "inclusions." But LUX misinterprets the language, emphasizing the words "other growth techniques" without acknowledging that the "other growth techniques" must be those "for which a transition to a three-dimensional growth mode has been observed." *See Phillips*, 415 F.3d at 1316 ("In light of the statutory directive that the inventor provide a 'full' and 'exact' description of the claimed invention, the specification necessarily informs the proper construction of the claims.").

B. LUX's proposed construction ignores what its brief acknowledges, that the way the inclusions are formed matters.

On at least one point, BrightBlue and LUX are in agreement. LUX correctly discerns that the method by which the inclusions are formed is important to defining what the inclusions are. But LUX's proposed construction is *not limited that way*. BrightBlue's proposed construction ("grown using three-dimensional nucleation and then buried by a different material") accounts for the way the inclusions are formed. LUX's does not. LUX proposes "a crystal or a fragment of a crystal *found within* another crystal." This definition speaks to where the inclusion is, not how the inclusion was formed. LUX's mistake is significant. Its proposed construction embraces the prior art: a quantum dot formed by lithographic techniques would indeed be "a crystal or a fragment of a crystal found within another crystal." But lithographically formed quantum dots were disclaimed during prosecution. '742 File History (Exhibit 3 at 4-5) (arguing that the method for making the inclusions was the key difference from the prior art). For this reason alone, LUX's proposal cannot be correct. *See Ormco*, 498 F.3d at 1316 ("The situation here involves specifications that in all respects tell us what the claims mean, buttressed by statements made during prosecution in order to overcome a rejection over prior art.").

C. The specification and the prior art consistently describe inclusions as "islands," which become inclusions when they are "buried by a different material."

According to the '742 patent, the three-dimensional inclusions are islands that are buried by a different material. Indeed, the '742 patent specification uses "inclusions" and "islands" interchangeably. (*E.g.* 4:61-68 & Fig. 5, 5:24-38.) Contrary to LUX's argument, "island" is not a terribly restrictive limitation on an inclusion's shape—islands can be hemispheres (as in the disclosed embodiment (4:63)), but also can be pyramids, rectangular solids, prisms, etc. *See* D. Bimberg *et al.*, QUANTUM DOT HETEROSTRUCTURES 5, 38-39, 43 (1999) (Exhibit 6). "Island" is a construction that is true to the specification and will assist the jury in evaluating whether the '742 patent is valid or infringed in a way that LUX's "crystal fragment" proposal will not.

After the islands are grown, the '742 patent explains that they are buried by depositing a different material over them. The inclusions are "buried inside the active layer" after they are formed using three-dimensional nucleation. (5:36-37; *see also* 3:20-23; 5:12-17.) LUX's dictionary supports the idea that inclusions are buried in the process of growing the surrounding material; it says the inclusions are "trapped . . . during solidification." The word "buried" in BrightBlue's proposed construction plays the same role as "trapped" in LUX's brief—both show that the process of forming the sub-layer atop the InAs islands is what makes the island an inclusion.

LUX's proposed construction, in contrast, places no limitations on how the inclusions are formed. LUX would require only that the inclusions be "found within" the surrounding material, without any reference to how they came to be found there. The construction "buried by a different material" is true to the intrinsic evidence by ensuring that the construction of three-dimensional inclusion reflects the formation of the inclusions and the distinction drawn between inclusion material and sub-layer material.

The extrinsic evidence is consistent with the inclusions being islands buried by different material. *See Phillips*, 415 F.3d at 1319 ("[E]xtrinsic evidence can help educate the court regarding the field of the invention and can help the court determine what a person of ordinary skill in the art would understand claim terms to mean . . . ."). Other references also used "islands" to refer to the natural result of a three-dimensional growth mode, as opposed to two-dimensional growth. For example, a 1985 paper disclosed that "two kinds of nucleation have been identified when InAs is grown on a GaAs substrate, depending on growth conditions. For ultra-thin InAs films a two-dimensional growth (2D) is observed. When the layer thickness is increased, the strains in the epitaxial film induce a transition from the 2D to a three-dimensional (3D) growth with island formation under arsenic-rich conditions." L. Goldstein *et al.*, *Growth by molecular beam epitaxy and characterization of InAs/GaAs strained-layer superlattices*, 47 APPL. PHYS. LETT. 1099, 1099 (1985) (Exhibit 7). So based on the extrinsic evidence and the '742 specification, the phrase "three-dimensional inclusions" would have been understood by persons of ordinary skill in the art to refer to islands formed by three-dimensional nucleation and then buried by a different material.

IV. CONCLUSION

BrightBlue respectfully requests that the Court adopt its proposed construction, and instruct the jury accordingly.

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BRIGHTBLUE CORPORATION,	)	**JURY TRIAL DEMANDED**
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	)	
Defendant.	)	

PLAINTIFF'S REPLY CLAIM CONSTRUCTION BRIEF

I. INTRODUCTION

BrightBlue's Responsive Brief shows a selective focus on specific characteristics of preferred embodiments of the '742 patent, and is therefore not properly grounded in the intrinsic evidence. In contrast, LUX's proposed constructions clearly define the scope of the claimed invention and are properly grounded in the intrinsic evidence. Therefore, the Court should adopt LUX's constructions and decline to import a number of improper claim limitations as proposed by BrightBlue.

II. LUX'S REPLY TO BRIGHTBLUE'S PROPOSED CONSTRUCTION OF "INCLUSION"

BrightBlue's proposed construction of "three dimensional inclusion" confuses an exemplary means of forming an inclusion—in this case, three-dimensional growth—with the inclusion itself. This mischaracterizes the role of this term in the patent. During prosecution, the applicants described the growth of inclusions only by specifying that the sub-layers (including inclusions) are "deposited successively during growth." In contrast, neither the term "inclusion" nor the larger phrase "three dimensional inclusion" were ever amended during prosecution.

This is important, because original claim 1, as BrightBlue correctly points out, was read by the Examiner to cover inclusions that are "lithographically formed." The text of original claim 1 reads as follows:

> A structure having plural layers in semiconductor material, one of said layers comprising *three-dimensional inclusions* in a semiconductor material having a narrower forbidden band than the forbidden band of the material of said layer.

'742 File History (Exhibit 2 at 13) (emphasis added). To overcome the Examiner's rejection, the language "plural substantially parallel sub-layers deposited successively during growth of said one layer, each of said sub-layers having" was added to the claim. *See* '742 File History (Exhibit 2 at 45).

No change was made to the phrase "three-dimensional inclusions." In light of this amendment, the prosecuting attorney observed that "the wording of claim 1 has been clarified to define over the cited references." '742 File History (Exhibit 2 at 46). Thus the term "inclusion" or "three dimensional inclusions" was *never narrowed during prosecution*.

Furthermore, the specification does not "require" that inclusions are made by the exemplary three-dimensional growth. *See Candela Corp. v. Palomar Med. Techs., Inc.*, No. 9:06-CV-277, 2008 U.S. Dist. LEXIS 59860, at *15 (E.D. Tex. Aug. 6, 2008).

Finally, the term "three-dimensional" does not require construction in concert with the term "inclusion." Any intimation that it refers to the method by which inclusions are made is inaccurate and confusing, as discussed above. Contrary to BrightBlue's arguments, giving "three-dimensional" its ordinary meaning does not render the term meaningless. It simply specifies—correctly—that inclusions are not flat.[1] And a jury can distinguish between flat and three-dimensional.

III. CONCLUSION

For the foregoing reasons, and those expressed in LUX's opening brief, LUX respectfully requests that the Court adopt LUX's proposed constructions, and reject BrightBlue's proposed constructions.

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[1] BrightBlue's own extrinsic evidence clearly supports this point. *See* AMERICAN HERITAGE DICTIONARY 1801 (defining "three-dimensional" as both "of, relating to, *having*, or existing in three dimensions" and "having or appearing to have *extension in depth*") (Exhibit 6) (emphasis added).

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Defendant.	)	

JOINT CLAIM CONSTRUCTION STATEMENT

Claim Language in Dispute	Plaintiff's Proposed Construction and Supporting Intrinsic Evidence	Defendant's Proposed Construction and Supporting Intrinsic Evidence	Consequence of Construction
Inclusion three-dimensional inclusions	An "inclusion" means a "a crystal or a fragment of a crystal found within another crystal." Given this construction of "inclusion," the phrase "three-dimensional inclusions" does not require further construction by the Court. **Supporting evidence:** <u>Specification:</u> 3:5-10, 4:55-61, 5:33-37, 5:37-38, 5:41-43. <u>Claims:</u> Claim 5.	"Three-dimensional inclusions" are islands grown using three-dimensional nucleation and then buried by a different material. **Supporting evidence:** <u>Specification:</u> 2:64-3:10; 3:11-14; 3:15-23; 3:48-52; 4:55-68; 5:1-35; 5:36-38; 5:52-55; 5:55-59; 6:9-16; 6:24-25; 6:36-41; Figs. 5:8, 6:P1-PN, 7:P1-PN, 8:8, 9:8, 10:8 <u>Prosecution History:</u> Response to April 22, 1991 Office Action (July 22, 1991) at 4-5.	Defendant contends that under its construction summary judgment of noninfringement is proper and under either construction summary judgment of invalidity would be proper. Plaintiff contends that under either construction no summary judgment would be proper.

Respectfully submitted,

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LUX, INC.

Attorneys for Defendant
BRIGHTBLUE CORP.

United States Patent [19]
Gerard et al.

[11] **Patent Number: 5,075,742**
[45] **Date of Patent: Dec. 24, 1991**

[54] **SEMICONDUCTOR STRUCTURE FOR OPTOELECTRONIC COMPONENTS WITH INCLUSIONS**

[75] Inventors: **Jean-Michel Gerard; Claude Weisbuch,** both of Paris, France

[73] Assignee: **French State represented by the Minister of the Post, Telecommunications and Space,** Issy-Les-Moulineaux, France

[21] Appl. No.: **639,530**

[22] Filed: **Jan. 10, 1991**

[30] **Foreign Application Priority Data**

Jan. 10, 1990 [FR] France 90 00229

[51] **Int. Cl.**^{5} **H01L 33/00**
[52] **U.S. Cl.** **357/17**; 372/48; 372/43; 372/45; 357/16
[58] **Field of Search** 357/16, 17; 372/43, 372/44, 45, 46, 47, 48, 49, 50

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63-156363 6/1988 Japan 357/16

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Marinace et al., "Ge Inlays in a GaAs Matrix by Solvent Evaporation," IBM Technical Disclosure Bulletin, vol. 6, No. 2, Jul. 1963, p. 81.

Primary Examiner—William Mintel
Attorney, Agent, or Firm—Fleit, Jacobson, Cohn, Price, Holman & Stern

[57] **ABSTRACT**

The object of the invention is to reduce the influence of dislocations on the functioning of structures for optoelectronic component, such as laser, made from semiconductor materials. Accordingly, one of the lasers of such a structure comprises three-dimensional inclusions in a semiconductor material with a thinner forbidden band than the forbidden band of the layer material. The inclusions are e.g. distributed over several planes of the active layer of a laser, and may be in InAs introduced into a layer in GaAs.

5 Claims, 3 Drawing Sheets

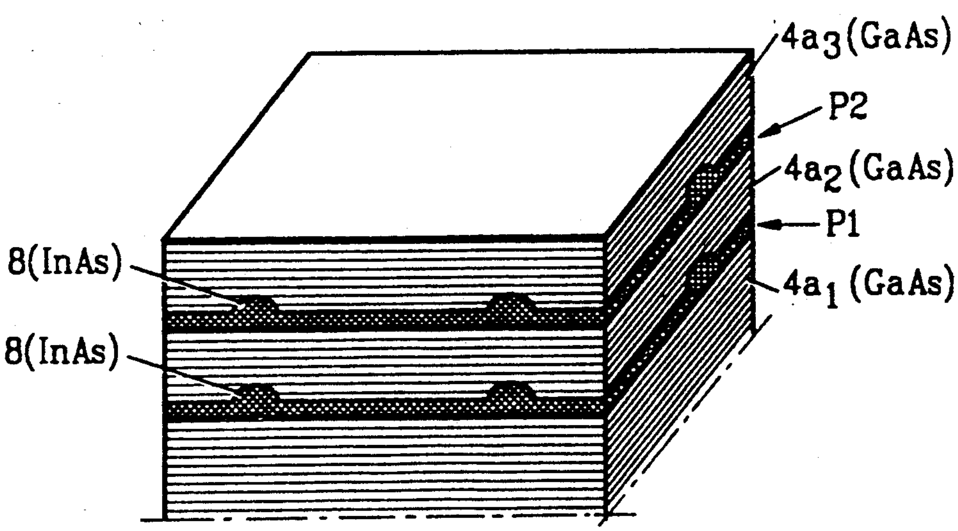


FIG. 1 (PRIOR ART)

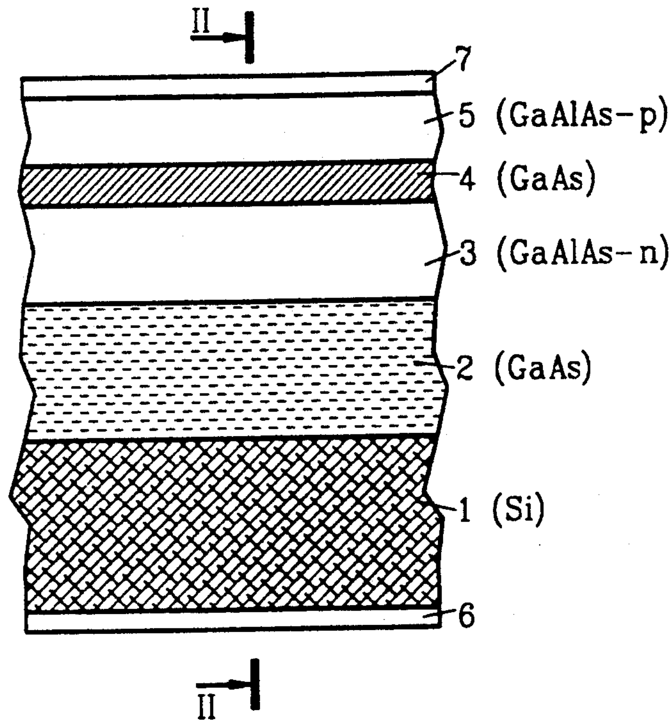


FIG. 2
(PRIOR ART)

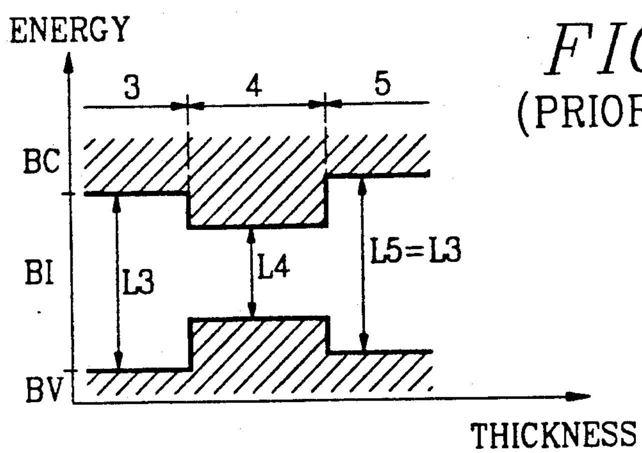


FIG. 3
(PRIOR ART)

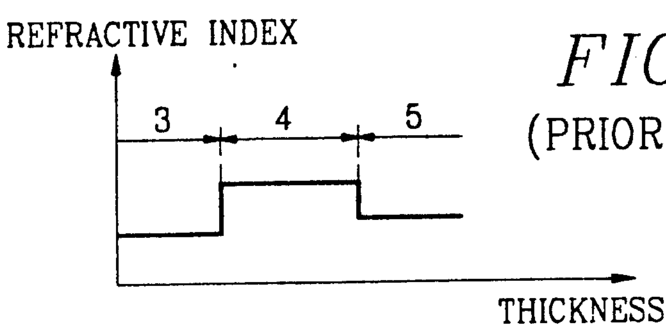


FIG. 4

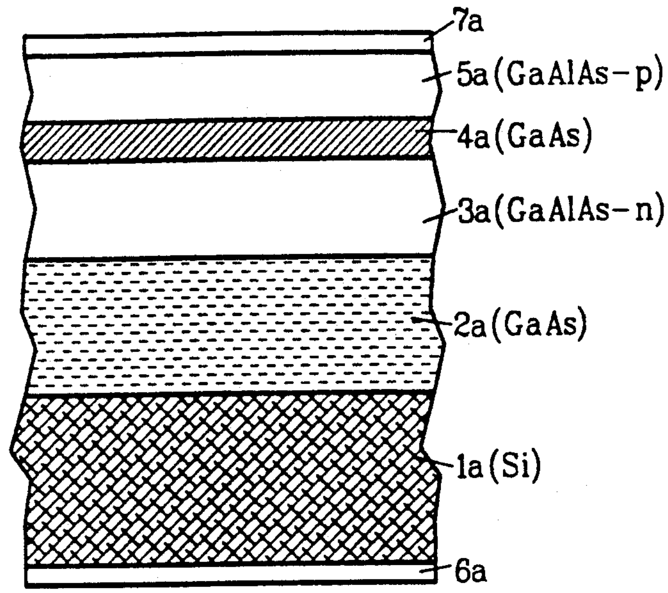


FIG. 5

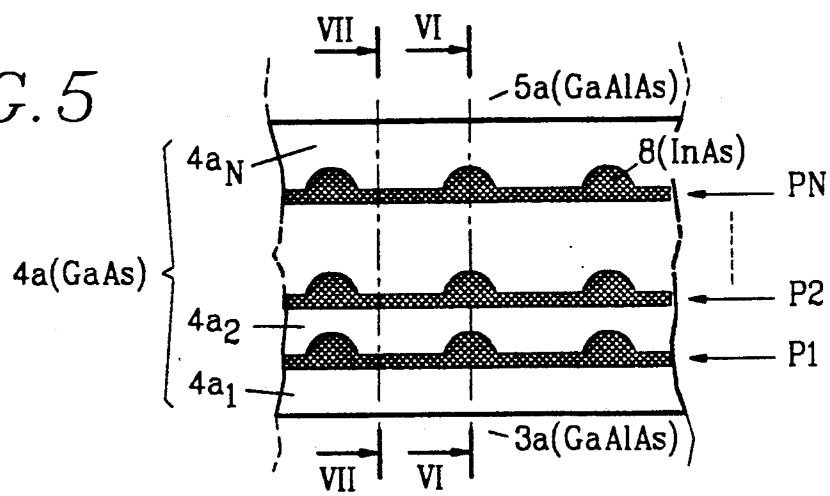


FIG. 6

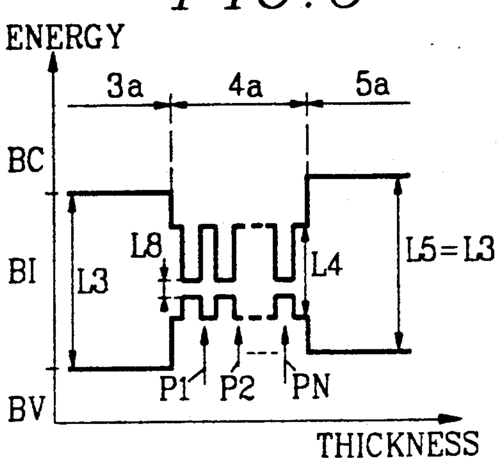


FIG. 7

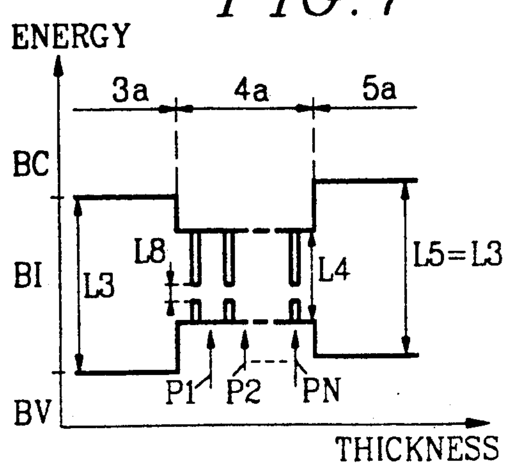


FIG. 8

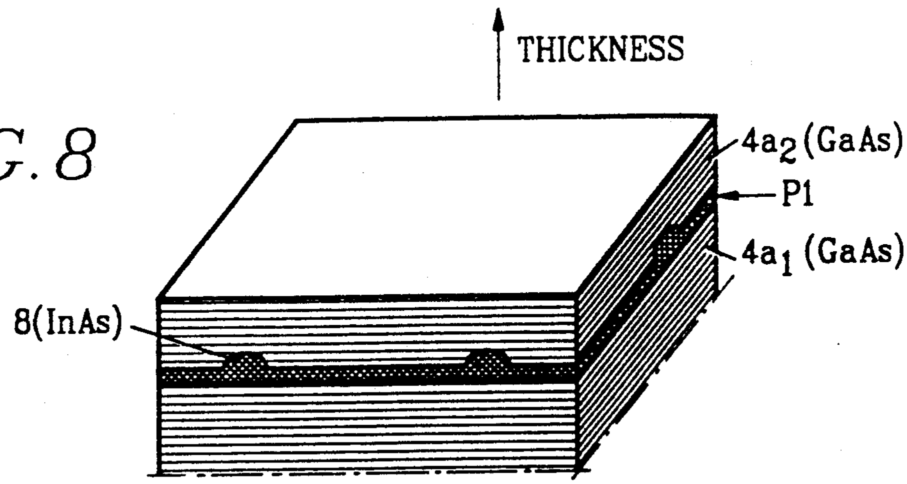


FIG. 9

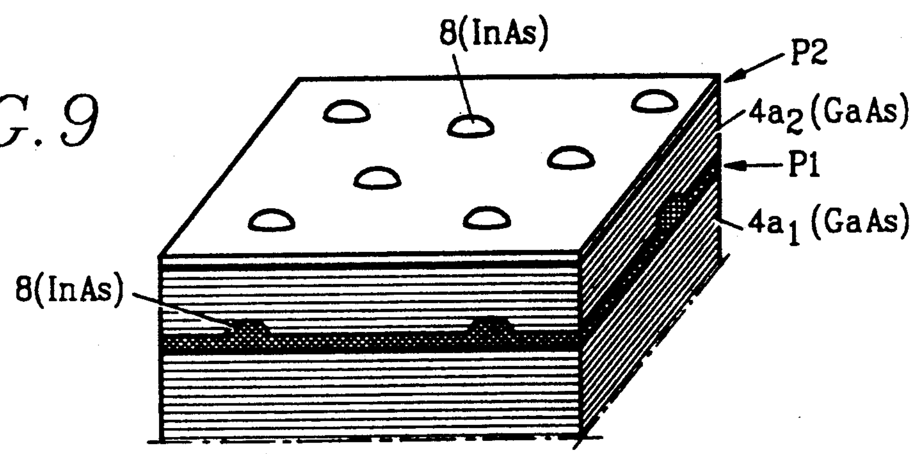
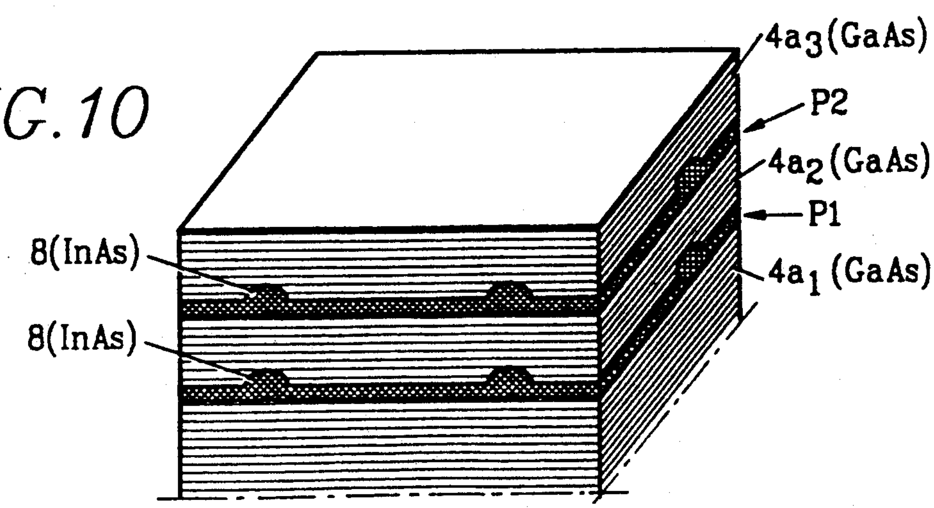


FIG. 10



SEMICONDUCTOR STRUCTURE FOR OPTOELECTRONIC COMPONENTS WITH INCLUSIONS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a multilayer structure in semiconductor material, especially for a solid state laser. More generally, the invention has applications in optoelectronics, and monolithic integration in opto- and microelectronics.

2. State of the Prior Art

Silicon Si and gallium arsenide GaAs are currently the most widely used semiconductor materials. Although a very high scale of integration has been obtained in microelectronics using silicon, optoelectronics has developed from heterostructure lasers with semiconductor materials from groups III and V of the Mendeleevian classification, such as GaAs/GaAlAs on GaAs substrate and such as GaInAs/AlInAs or GaInAs/InP on InP substrate. The integration on a common substrate of optoelectronic and microelectronic devices with complementary functions produced from different materials, e.g. material from groups III and V and silicon, is a particularly appealing perspective which has given rise to intensive research work in recent years.

A silicon substrate has numerous advantages: solidity, perfection, high thermal conductivity, low cost, etc. It is mainly the deposition of III-V compounds on silicon that has mainly been studied. Much progress has been achieved concerning this type of epitaxial growth and has enabled the obstacles encountered to be partially overcome: the difficulty in depositing a polar material such as III-V semiconductors on a non-polar material such as silicon, and the major lattice parameter difference between these, e.g. 4% for GaAs on silicon.

In particular, this mismatch implies the presence of a very high quantity of dislocations in the first tens of nanometers of the epitaxially deposited material. These dislocations can be due to the preparation of the state of the surface upon which the epitaxial growth is carried out, and/or to a degradation over time of the crystallographic quality of the epitaxial semiconductor. Whatever their origin, these dislocations beget local inhomgeneities and can develop.

For instance, when the crystalline lattice parameter of a layer is lower than that of a second layer, the first layer is subjected to tension and dislocations occur in the layer interface. If the first layer is the active layer of a laser component, the performances of the laser component are highly dependent on the number of dislocations present. These defects do, of course, affect the threshold current of this component with minority carriers, but also affect its ageing. When the component is operating, the presence of an electric field, and of high photon and carrier densities also help the displacement of existing defects and assist the generation of new defects.

For conventional optoelectronics applications, optoelectronic components are produced from III-V semiconductor heterostructures, such as GaAs/GaAlAs on GaAs substrate and such as GaInAs/AlInAs or GaInAs/InP on InP substrate. The dislocation rates obtained during the growth of these structures by conventional techniques, like molecular beam epitaxy and vapor phase epitaxy from organometallic compounds,

are in the region of $10^4/cm^2$. The rates are compatible with proper functioning of these optoelectronic components, as witnessed by the large-scale commercial use of some of these, such as GaAs/GaAlAs laser diodes with 0.85-μm wavelength; however, in certain cases, the displacement and multiplication of the dislocations during operating of the components have been observed and correlated with lifetime problems of these components. The dislocation-related problems, latent in this instance, become crucial if these defects are more numerous in the material used.

In the case of the growth of a III-V material on silicon, it is therefore primordial to seek as low a dislocation rate as possible in the structure. The dislocation rates in the superficial layer of the material remain in the region of 10^6 to 10^7 dislocations per cm^2. The number of dislocations tends to decrease with the thickness of the deposit, but depositions cannot exceed 4 to 5 microns of material. Beyond that, the very major difference in coefficients of expansion between the silicon and the III-V material entails the formation of numerous cracks in the epitaxial layer when the growth temperature, in the region of 500° to 600° C., drops to room temperature. This failure of the attempts to reduce the number of dislocations is charged with consequences as regards the stability of laser components fabricated on silicon substrates.

To illustrate the results obtained, consideration is directed to the case of a GaAs structure on Si, which is the case that has been studied most intensely. No instance of room-temperature continuous-emission operation has been observed to date for double heterostructure lasers, as the component degrades below the laser threshold. On the other hand, a room-temperature operation in the pulsed mode, then in the continuous mode for short periods in the region of one minute has been observed for quantum well lasers, i.e., structures with confinement separated by index gradient. The reduction of the dimensions of the active layer is therefore clearly beneficial for the operating of the optoelectronic component. This result is related to several favourable factors. The use of the separate confinement concept brings about a reduction of the threshold current of the component, and therefore an increased stability of the latter. Moreover, there is a reduction in the size of the active layer which is the only region of the structure in which the two types of carriers are simultaneously present: the diffusion of the carriers before recombination then occurs in a plane and the dislocations no longer occur in the carrier capture except by their line fragment intersecting the active layer. However, even with these quantum well structures, the components obtained are not very stable, and have lifetime-related problems.

OBJECT OF THE INVENTION

The main object of this invention is to reduce the influence of dislocations on the operating of structures for optoelectronic components, such as lasers, fabricated from semiconductor materials.

SUMMARY OF THE INVENTION

Accordingly, there is provided a structure having plural layers in semiconductor material wherein one of the layers comprises three-dimensional inclusions in a semiconductor material having a narrower forbidden band (bandgap) than the forbidden band of the material of said layer.

Preferably, the layer comprising the inclusions constitutes the active layer of an optoelectronic component, such as a laser. The inclusions ensure a function of traps for the carriers, thereby avoiding diffusion of the latter towards the core of the dislocations and the associated nonradiative centers. The inclusions are the site of the radiative recombination between electrons and trapped holes leading to the laser gain.

The inclusions are inserted during growth, by using the three-dimensional nucleation mode observed during the epitaxy of III-V materials that are highly mismatched with regard to the substrate used. Accordingly, a method for fabricating a multilayer structure embodying the invention comprises the two following successive steps during the growth of the material constituting one of said layers:

interrupting at least once said growth, and

depositing a thin layer of the semiconductor material having a narrower forbidden band than the forbidden band of the material of said layer thereby constituting three-dimensional inclusions.

BRIEF DESCRIPTION OF THE DRAWINGS

Further features and advantages of the invention will be apparent from the following particular description of several preferred embodiments of this invention as illustrated in the corresponding accompanying drawings in which:

FIG. 1 is a schematic transverse cross-sectional view of a laser structure according to the prior art;

FIG. 2 is a thickness - quantum energy diagram of the structure according to FIG. 1, in correspondence with the line II—II in FIG. 1;

FIG. 3 is a thickness - refractive index diagram of the structure shown in FIG. 1, according to the line II—II;

FIG. 4 is a schematic transverse cross-sectional view of a multilayer structure in semiconductor material embodying the invention, of a similar type to that of FIG. 1;

FIG. 5 is a schematic detailed view of the active layer in the structure shown in FIG. 4;

FIGS. 6 and 7 are thickness - quantum energy diagrams of the structure shown in FIG. 4, in correspondence with lines VI—VI and VII—VII in FIG. 5, respectively; and

FIGS. 8, 9 and 10 are schematic views in perspective of the structure in FIG. 4 for illustrating the state of the active layer in FIG. 5 before and after deposition of inclusions in a plane and after deposition of a sublayer of active layer on the inclusions, respectively.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

As appears by comparison of FIGS. 1 to 4, a structure of a semiconductor laser according to the invention is similar to a known solid-state laser structure. The known structure comprises a semiconductor substrate 1 and a stacking of three or four layers in semiconductor material 2, 3, 4 and 5 placed on a major side of the substrate 1.

In the structure illustrated in FIG. 1, four layers 2 to 5 are provided and constitute a double heterostructure. The layers 2 to 4 are in semiconductor material offering narrow forbidden bands (bandgap) BI between valence band BV and conduction band BC, and high refractive indexes; the semiconductor material of the layers 2 and 4 can be GaAs. The two other layers 3 and 5 are in semiconductor material with forbidden band widths L3 and L5 that are larger than the width of the forbidden band L4 of the layer 4, as shown in FIGS. 2 and 3, and low refractive indexes. The narrowness of the forbidden bands of the layers 2 and 4 is defined here in relation to largeness of the forbidden bands of the layers 3 and 5. Under these conditions, the layers 3 and 5 confine, as is known, a laser beam propagating itself in the active layer 4 intermediate between the layers 3 and 5.

According to a preferred embodiment, the stacking of layers 2 to 5 constitutes a double heterostructure GaAs/GaAlAs formed on a substrate in silicon Si.

The layer 2 is of the monolayer or multilayer type and is epitaxially deposited directly on said major side of the substrate 1 and is in GaAs. The layer 2 constitutes a buffer layer as un-dislocated as possible whose sole purpose constituted by the layers 3, 4 and 5. According to certain embodiments, the layer 2 can be omitted.

The active layer 4 is also in GaAs, and is interposed between the thick layers 3 and 5 and is thinner than layers 3 and 5.

The layers 3 and 5 are in ternary alloy GaAlAs with a lower refractive index than that of the active layer 4 interposed between the layers 3 and 5. The layers 3 and 5 are doped with opposite conductivity impurities, respectively of type n and p. The injected electrons and holes are thus confined and recombine in the active layer 4 which ensures the confinement of the optical wave. In the layer 4 which constitutes the active region of the laser, energy is transferred to the electromagnetic wave by the recombination of the carriers.

To be complete, it should be noted that the invention may apply to any type of known structure in semiconductor materials for laser or optoelectronic components such as optical modulators or optical switches. In particular, the confining layers 3 and 5 may each be constituted by several layers of the same material but with different doping concentrations, and the upper layer 5 may be covered with other layers in semiconductor material that is different and/or of different conductivity, or even with an insulating layer such as SiO_2 or Si_3N_4. Two thin metallic layers 6 and 7 forming electrodes are, of course, provided on both sides of the stack of layers.

Turning to FIG. 4, the semiconductor laser structure embodying the invention comprises a substrate *1a*, and superposed layers *2a*, *3a*, *4a* and *5a* as well as electrodes *6a* and *7a* which are arranged in relation to one another in the same way as the substrate 1, the layers 2 to 5 and the electrodes 6 and 7 in the known structure shown in FIG. 1. All the layers, with the exception of the layer *4a*, are identical to the corresponding layers in the known structure.

According to the invention, the active layer *4a* is modified by comparison with the previous layer 4, by punctual inclusions 8 in a semiconductor material, such as indium arsenide InAs having, as shown in FIG. 6, a smaller width of forbidden band L8 than that L4 of the semiconductor material of the active layer *4a*, such as gallium arsenide GaAs. As shown in detail and schematically in FIG. 5, the inclusions 8 of InAs form islands substantially of a semi-spherical cap shape which are spread over the layer *4a*, with a substantially uniform density, in several planes parallel to the confinement layers *3a* and *5a*. To avoid overloading of FIG. 5, only three planes P1, P2, PN of inclusions 8 have been illustrated in it.

The fabrication of the semiconductor laser embodying the invention is analogous to that of a laser of the same type according to the prior art, with the exception of the formation step of the active layer **4***a*. The entire laser structure is produced by the same growth technique, e.g. molecular beam epitaxy MBE, or by vapor phase epitaxy in another embodiment.

The growth by molecular beam epitaxy of the material GaAs constituting the layer **4***a* begins at the end of the formation of the confinement layer **3***a*. When the thickness of this layer **4***a* reaches each of the planes **P1** to PN, the growth is interrupted at this point of the structure, as shown in FIG. **8** for the plane P2. A thin layer of InAs is deposited on the surface of the "sub-layer" thus formed $4a_1$, $4a_2$, . . . of the active layer **4***a*. The material, InAs, has a lattice that is highly mismatched with GaAs, in the region of 7%, which strongly influences the InAs growth mode. The first molecular layer **P1** of InAs, in practice having a thickness of approximately 0.3 nm, elastically accommodates this lattice parameter difference. However, from the second monolayer on, corresponding to the plane P2, a transition to a three-dimensional growth mode is observed at the usual growth temperature of 500° to 550° C. Islands **8** of indium arsenide InAs form at the surface. During an observation of these islands with a Scanning Transmission Electron Microscope (STEM), the size of the InAs islands is seen to be fairly homogeneous, and the distribution of the islands is relatively uniform on the surface of the sample, as shown at the level of the second active sub-layer $4a_2$ in FIG. **9**. In practice, each inclusion is inscribed in a small paving with a size of $5\times5\times2$ nm^3 approximately, and the inclusions are spread over one or plural planes, such as the planes P1, P2 and PN illustrated in FIG. **5**. After each deposition of inclusions in a plane, the epitaxial growth of GaAs is again performed so as to form another active sub-layer. The inclusions **8** are thus buried inside the active layer **4***a*. Constrained within the GaAs lattice, the inclusions do not however contain any dislocation.

As shown in FIGS. **6** and **7**, the indium arsenide InAs has a smaller forbidden band energy (bandgap energy) than that of gallium arsenide GaAs. The inclusions **8** are therefore more attractive for the electrons and the holes. A photoluminescence study of InAs structures in GaAs shows that the trapping of carriers by the inclusions is very efficient, which is translated by a very intense luminescence due to the inclusions, and a very small contribution of the GaAs lattice, and that the optical quality of these structures is very good. A transmission study of these structures shows that this luminescence is intrinsic, i.e., linked to the presence of a high density of states in conjunction with the luminescence energy. Finally, the size of the inclusions and consequently the position of the associated luminescence line depend on the quantity of InAs deposited after the transition to a three-dimensional growth mode.

Furthermore, the density of the InAs inclusions **8** in a plane **P1** to PN is very high, approximately 10^{12}/cm^2, and is particularly high compared with the number of dislocations in known GaAs structures on Si, typically in the region of 10^6/cm^2. The inclusions **8** situated near a dislocation therefore only represent a tiny fraction of their population. The injected carriers therefore have a very high probability of being trapped by an inclusion rather than by a dislocation, and by an intact inclusion rather than by an inclusion perturbed by the proximity of a dislocation. Finally, the presence of highly constrained areas in the structure around the InAs inclusions can inhibit the propagation of existing dislocations.

The confinement factor Γ which is defined as the fraction of the optical wave lying in the active layer **4***a*, is low for the structure embodying the invention, though it is close to 1 in the double heterostructure as shown in FIG. **1**. For a plane of inclusions **P1** to PN, the confinement factor is close to that of a structure with an 0.6-nm wide quantum mono-well. On the other hand, the gain per unit of volume of the active medium g_v increases very significantly for such a laser with quantum boxes. To obtain the same amplification of the optical wave in the cavity, the modal gain $\Gamma.g_v$ must be the same for the two structures. It is then necessary to multiply the inclusion planes in the structure in order to increase the factor of optical confinement. This requirement is met e.g. by forming N=10 to 40 planes **P1** to PN of InAs inclusions **8** in a GaAs cavity having a thickness of 200 nm.

Though the above description refers to a GaAs/-GaAlAs heterostructure, it is possible according to the invention to introduce inclusions in the active layer of other known heterostructures. Among the semiconductor alloy heterostructures of III-V compounds, mention can be made of the laser structures (InGa)As/(InAl)As or (InGa)As/InP on highly mismatched Si or GaAs substrate. InAs inclusions can be fabricated here according to the method embodying the invention. A quaternary alloy such as GaInAsP or InGaAlAs can be provided instead of a binary or ternary alloy. The method embodying the invention is also implemented in matched structures when the commercially available substrate used is of insufficient quality, i.e., when it has a high dislocation rate.

The invention also applies to laser structures usually used for optimizing the optical confinement factor and the collection of carriers, such as heterostructures with separate confinement, with confinement separated by index gradient, etc.

It is possible to apply the invention within the framework of other growth techniques for which a transition to a three-dimensional growth mode has been observed. The fabrication of a GaAs laser structure on Si with InAs inclusions is, for instance, also possible in vapor phase epitaxy from organometallic compounds.

Generally speaking, the present invention makes it possible to reduce the degradation of performances of optoelectronic components when this degradation is due to dislocations, whether it is a question of the increase of their number or their propagation, since the influence of dislocations is reduced. This aspect is important for the power application of laser components.

What we claim is:

1. A structure having plural layers in semiconductor material, one of said layers comprising plural substantially parallel sub-layers deposited successively during growth of said one layer, each of said sub-layers having three-dimensional inclusions in a semiconductor material and a narrower forbidden band gap than a forbidden band gap of said one layer.

2. The structure claimed in claim **1**, wherein the size of each of said inclusions is in the neighborhood of 50 nm^3.

3. The structure claimed in claim **1**, wherein said layer comprising said inclusions is an active layer of an optoelectronic component.

4. The structure claimed in claim **1**, wherein said inclusions comprise indium arsenide.

5. The structure claimed in claim **1**, wherein said layer comprising said inclusions comprises one of the following semiconductor materials: InGaAs, GaAs, GaInAsP, InGaAlAs.

* * * * *

Subst A1

WHAT WE CLAIM IS:

1 - A structure having plural layers in semiconductor material, one of said layers comprising three-dimensional inclusions in a semiconductor material having a narrower forbidden band than the forbidden band of the material of said layer.

2 - The structure claimed in claim 1, wherein said inclusions are distributed over several substantially parallel planes.

a

2 ~~3~~ - The structure claimed in claim 1, wherein the size of each of said inclusions is in the neighborhood ~~region~~ of 50 nm^3.

3 ~~4~~ - The structure claimed in claim 1, wherein said layer comprising said inclusions is an active layer of an optoelectronic component.

a

4 ~~5~~ - The structure claimed in claim 1, wherein said inclusions comprise ~~are in~~ indium arsenide.

a

5 ~~6~~ - The structure claimed in claim 1, wherein said layer comprising said inclusions comprises ~~is in~~ one of the following semiconductor materials: InGaAs, GaAs, GaInAsP, InGaAlAs.

7 - A method for fabricating a structure having plural layers in semiconductor material, said method comprising the two following successive steps during the growth of the material constituting one of said layers :

- interrupting at least once said growth, and
- depositing a thin layer of the semiconductor material having a narrower forbidden band than the forbidden band of the material of said layer thereby constituting three-dimensional inclusions.

8 - The method claimed in claim 7, wherein said growth results from one of molecular beam and vapor phase epitaxies.

9 - The method claimed in claim 8, wherein said expitaxy uses organometallic compounds.

PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of:

Jean-Michel GERARD et al.

Serial No.: 07/639,530

Filed: January 10, 1991

MAIL RO JUL 22 1991 PAT. & TRADEM.

Group Art Unit: 258

#7/a

Examiner: W. Mintel

For: SEMICONDUCTOR STRUCTURE FOR OPTOELECTRONIC COMPONENTS

B.Q. 7/24/91

RECEIVED

JUL 23 1991

GROUP 250

RESPONSE TO FIRST OFFICE ACTION

Honorable Commissioner of
Patents and Trademarks
Washington, DC 20231

Sir:

Responsive to the Official Action mailed April 22, 1991, please amend the above-identified application as follows:

ABSTRACT OF THE DISCLOSURE

Please amend the Abstract as follows:

Page 1, line 3, change "layers" to --lasers--.

IN THE SPECIFICATION

Please amend the specification as follows:

Page 2, line 3, after "for", insert --a--;

line 4, delete "largely concerning";

line 8, change "Though" to --Although--;

line 12, change "same" to --common--; and

line 31, delete "a" (second occurrence).

Page 4, line 1, change "let us consider" to --

consideration is directed to--;

line 21, change "laser" to --lasers--;

line 29, after "as", insert --a--; and

line 30, delete "a".

Page 5, line 17, change "transversal" to --transverse--;

line 20, after "II-II", insert --in Fig. 1--; and

line 23, change "transversal" to --transverse--.

Page 6, line 10, change "According to the embodiment" to --In the structure--; and

line 31, change "them" to --layers 3 and 5--.

Page 7, line 2, change "buried" to --interposed--; and

line 28, change "in" to --of a--.

Page 8, line 6, change "according to" to --in--.

Page 9, line 3, change "in" to --is--.

<u>IN THE CLAIMS</u>

Kindly cancel claims 2 and 7-9 without prejudice and amend claims 1, 3, 5 and 6 as follows:

1. (Amended) A structure having plural layers in semiconductor material, one of said layers comprising <u>plural substantially parallel sub-layers deposited successively during growth of said one layer, each of said sub-layers having</u> three-dimensional inclusions in a semiconductor material <u>and</u> [having] a narrower forbidden band <u>gap</u> than [the] <u>a</u> forbidden band <u>gap</u> of [the material of] said <u>one</u> layer.

a

Claim 3, line 2, change "region" to --neighborhood--.

Claim 5, line 1, change "are in" to --comprise--.

Claim 6, line 2, change "is in" to --comprises--.

REMARKS

In view of the above amendments, favorable reconsideration of the application is respectfully requested. The following items deal item by item with the matters noted in the action.

Firstly, regarding the objections to the disclosure, the corrections noted by the Examiner have been attend to and the specification has been carefully gone through in order to correct additional grammatical errors and inconsistencies.

Next, the Examiner rejected claims 1-6 under 35 U.S.C. 112. Again, each of the matters noted by the Examiner has been corrected in the manner indicated and therefore it is believed that this rejection has been overcome.

Finally, the Examiner rejected claims 1-4 and 6 under 35 U.S.C. 102 as being anticipated by Cibert et al. or Iwata and rejected claim 5 under 35 U.S.C. 103 as being unpatentable over Cibert et al. or Iwata in view of Tokuda et al.

By this amendment, claim 2 is cancelled and the subject matter thereof has been effectively included in claim 1. Also, the wording of claim 1 has been clarified more clearly to define over the cited references and it is believed that the art rejections are thereby overcome, for the reasons set out below.

Claim 1 as amended, defines a structure having plural layers in semiconductor material, one of the layers comprising plural substantially parallel sub-layers deposited successively during growth of said one layer, each of the sub-layers having three dimensional inclusions in a semi-conductor material and a narrower forbidden band gap than a forbidden band gap of the one layer. With respect, there is no disclosure or suggestion of the structure in the references cited by the Examiner.

Cibert et al. describes a method of fabricating a semiconductor structure enabling a confinement of carriers in an active layer following one or two degrees of freedom by using a "box" structure. According to the preferred embodiment, the active layer consists in GaAs and is inserted between two junctions GaAlAs. A mask is provided on a junction GaAlAs and offers windows. Ga^+ ions are injected with sufficient energy through the windows to reach the level of the active layer. Then, by annealing the semiconductor structure, Al are attracted until the active layer where Ga^+ have been implanted. Thus, the initial active layer, at the level of the windows formed by the mask, disappears and "boxes" are formed at the level of the mask. Thus, in structures such as lasers, the light is diffused from sections of said boxes.

The Cibert et al. method does not realize a multi-sub-layer active layer as defined in the present application because of the difficulty to inject ions Ga^+ at different planes with accuracy.

Concerning structure, Cibert et al. describes an active layer with successive active bars in the same plane while the subject application relates to an active layer having sub-layers in parallel planes.

It is noted that the kind of structure disclosed in Cibert et al. is herein discussed in "State of the Prior Art" and is known as "quantum well structure".

Iwata describes a semiconductor structure analogous to Cibert et al., i.e., including quantum well boxes formed by an injection of ions. These "boxes" are formed in active layer and have a forbidden band gap narrower than that of the active layer. Thus, electrons and ions are confined in said boxes.

It is important to note that there is a distinction between "inclusions" and boxes.

According to the invention, the deposit of a semiconductor material having a narrower forbidden band gap than the forbidden band gap of the "initial active layer" is realized during the semiconductor crystal growth.

The creation of boxes according to the cited references is performed after such growth by injecting ions.

The difference concerning the structure is that it is difficult to create a multi-sub-layer active layer because of high precision necessary to inject ions at different levels. Similar remarks apply to the Tokuda et al. reference.

In view of the above, it is believed that the claims as amended should be in condition for allowance and an early notification to that effect is respectfully requested.

Regarding the non-elected claims, these have been cancelled without prejudice to Applicant's right of filing a divisional application for the subject matter thereof.

Respectfully submitted,

FLEIT, JACOBSON, COHN, PRICE, HOLMAN & STERN

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JCH/DWS/ps
Dated: July 22, 1991

from an aircraft to destroy or reduce the utility of a target by the effects of combustion. { in'sen·dē,er·ē 'bäm }

incendiary file destroyer [ORD] An incendiary device designed for use in destroying combustible file material. { in'sen·dē,er·ē 'fīl di,stroi·ər }

incendiary grenade [ORD] Hand grenade designed to be filled with incendiary materials, or used primarily for incendiary purposes. { in'sen·dē,er·ē grə'nād }

incendiary rocket [ORD] A rocket with a warhead designed to produce an incendiary effect at the target. { in'sen·dē,er·ē 'räk·ət }

incentive wage system *See* wage incentive plan. { in'sen·tiv 'wāj ,sis·təm }

inceptisol [GEOL] A soil order characterized by soils that are usually moist, with pedogenic horizons of alteration of parent materials but not of illuviation. { in'sep·tə,sȯl }

incertae sedis [SYST] Placed in an uncertain taxonomic position. { iŋ¦kər,tī 'sā·dəs }

inch [MECH] A unit of length in common use in the United States and Great Britain, equal to 1/12 foot or 2.54 centimeters. Abbreviated in. { inch }

inching *See* jogging. { 'inch·iŋ }

inch of mercury [MECH] The pressure exerted by a 1-inch-high (2.54-centimeter) column of mercury that has a density of 13.5951 grams per cubic centimeter when the acceleration of gravity has the standard value of 9.80665 m/s^2 or approximately 32.17398 ft/s^2; equal to 3386.388640341 newtons per square meter; used as a unit in the measurement of atmospheric pressure. { 'inch əv 'mər·kyə·rē }

incidence angle *See* angle of incidence. { 'in·səd·əns ,aŋ·gəl }

incidence matrix [MATH] In a graph the $p \times q$ matrix (b_{ij}) for which $b_{ij} = 1$ if the ith vertex is an end point of the jth edge, and $b_{ij} = 0$ otherwise. { 'in·səd·əns ,mā·triks }

incidence plane *See* plane of incidence. { 'in·səd·əns ,plān }

incidental element *See* irregular element. { ¦in·sə¦dent·əl 'el·ə·mənt }

incident field intensity [ELECTROMAG] Field strength of a sky wave without including the effects of earth reflections at the receiving location. { 'in·sə·dənt 'fēld in,ten·səd·ē }

incident light [OPTICS] The direct light that falls on a surface. { 'in·sə·dənt ¦līt }

incident power [ELEC] Product of the outgoing current and voltage, from a transmitter, traveling down a transmission line to the antenna. { 'in·sə·dənt ¦pau̇·ər }

incident wave [ELECTR] A current or voltage wave that is traveling through a transmission line in the direction from source to load. [PHYS] A wave that impinges on a discontinuity, particle, or body, or on a medium having different propagation characteristics. { 'in·sə·dənt ¦wāv }

incineration [CHEM] The process of burning a material so that only ashes remain. { in,sin·ə'rā·shən }

incinerator [ENG] A furnace or other container in which materials are burned. { in'sin·ə,rād·ər }

incirrata [INV ZOO] A suborder of cephalopod mollusks in the order Octopoda. { ¦in·sə¦räd·ə }

incised [BIOL] Having a deeply and irregularly notched margin. [MED] Made by cutting, as a wound. { in'sīzd }

incised meander [GEOL] A deep, tortuous valley cut by a meandering stream that was rejuvenated. { in'sīzd mē'an·dər }

incision [MED] A cut or wound of the body tissue, as an abdominal incision or a vertical or oblique incision. { in'sizh·ən }

incisional hernia [MED] Abnormal protrusion of an organ through an operative or accidental incision. Also known as postoperative hernia; posttraumatic hernia. { in'sizh·ən·əl 'hər·nē·ə }

incisive canal [ANAT] The bifurcated bony passage from the floor of the nasal cavity to the incisive fossa. { in'sī·siv kə¦nal }

incisive foramen [ANAT] One of the two to four openings of the incisive canal on the floor of the incisive fossa. { in'sī·siv fə'rā·mən }

incisive fossa [ANAT] **1.** A bony pit behind the upper incisors into which the incisive canals open. **2.** A depression on the maxilla at the origin of the depressor muscle of the nose. **3.** A depression of the mandible at the origin of the mentalis muscle. { in'sī·siv 'fäs·ə }

incisor [ANAT] A tooth specialized for cutting, especially those in front of the canines on the upper jaw of mammals. { in'sīz·ər }

inclination [GEOL] The angle at which a geological body or surface deviates from the horizontal or vertical; often used synonymously with dip. [GEOPHYS] In magnetic inclination, the dip angle of the earth's magnetic field. Also known as magnetic dip. [MATH] **1.** The inclination of a line in a plane is the angle made with the positive x axis. **2.** The inclination of a line in space with respect to a plane is the smaller angle the line makes with its orthogonal projection in the plane. **3.** The inclination of a plane with respect to a given plane is the smaller of the dihedral angles which it makes with the given plane. [SCI TECH] **1.** Angular deviation of a direction or surface from the true vertical or horizontal. **2.** The angle which a direction or surface makes with the vertical or horizontal. **3.** A surface which deviates from the vertical or horizontal. { ,iŋ·klə'nā·shən }

inclination of axis [ASTRON] The angle between a planet's axis of rotation and the perpendicular to the plane of its orbit. { ,iŋ·klə'nā·shən əv 'ak·səs }

inclination of planetary orbits [ASTRON] The angle between the plane of the orbit and the plane of the ecliptic, which is the plane of the earth's orbit. { ,iŋ·klə'nā·shən əv ¦plan·ə,ter·ē 'ȯr·bəts }

inclination of the wind [METEOROL] The angle between the direction of the wind and the isobars. { ,iŋ·klə'nā·shən əv the 'wind }

incline [SCI TECH] An upward- or downward-sloping surface. { 'in,klīn }

inclined bedding [GEOL] A type of bedding in which the strata dip in the direction of current flow. { in'klīnd 'bed·iŋ }

inclined cableway [MECH ENG] A monocable arrangement in which the track cable has a slope sufficiently steep to allow the carrier to run down under its own weight. { in'klīnd 'kā·bəl,wā }

inclined contact [GEOL] A contact plane of gas or oil with water underlying, in which the plane slopes or is inclined. { in'klīnd 'kän,takt }

inclined drilling [ENG] The drilling of blastholes at an angle with the vertical. { in'klīnd 'dril·iŋ }

inclined extinction [OPTICS] Extinction in which the vibration directions are inclined to a crystal axis or direction of cleavage. Also known as oblique extinction. { in'klīnd ik'stiŋk·shən }

inclined orbit [AERO ENG] A satellite orbit which is inclined with respect to the earth's equator. { in'klīnd 'ȯr·bət }

inclined plane [MECH] A plane surface at an angle to some force or reference line. { 'in,klīnd 'plān }

inclined skip hoist [MIN ENG] A skip hoist that operates on steeply inclined rails placed on a mine pit slope or wall. { in'klīnd 'skip ,hȯist }

inclined-tube manometer [ENG] A glass-tube manometer with the leg inclined from the vertical to extend the scale for more minute readings. { in'klīnd ,tüb mə'näm·əd·ər }

incline shaft [MIN ENG] A shaft which has been dug at an angle to the vertical to follow the depth of the lode. { 'in,klīn ,shaft }

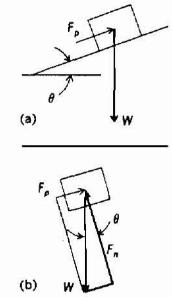
inclining experiment [NAV ARCH] An experimental determination of the weight of a ship and of the position of its center of gravity, in which a known weight, already aboard, is moved a measured distance perpendicular to the ship's centerline plane, and the resulting angle of list is measured. { in'klīn·iŋ ik,sper·ə·mənt }

inclinometer [ENG] **1.** An instrument that measures the attitude of an aircraft with respect to the horizontal. **2.** An instrument for measuring the angle between the earth's magnetic field vector and the horizontal plane. Also known as dip circle. **3.** An apparatus used to ascertain the direction of the magnetic field of the earth with reference to the plane of the horizon. { ,in·klə'näm·əd·ər }

inclusion [CRYSTAL] **1.** A crystal or fragment of a crystal found in another crystal. **2.** A small cavity filled with gas or liquid in a crystal. [CYTOL] A visible product of cellular metabolism within the protoplasm. [MET] An impure particle, such as sand, trapped in molten metal during solidification. [PETR] A fragment of older rock enclosed in an igneous rock. { in'klü·zhən }

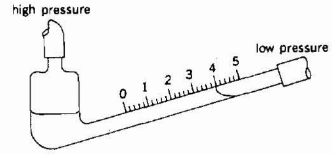
inclusion blennorrhea *See* inclusion conjunctivitis. { in'klü·zhən ,blen·ə'rē·ə }

INCLINED PLANE



Weight resting on an inclined plane (*a*) with principal forces applied, and (*b*) their resolution into normal force. θ is angle of inclination of plane, W is weight of body, F_p is force parallel to the surface, F_n is force normal to the surface.

INCLINED-TUBE MANOMETER



Drawing of inclined-tube manometer.

in•clude (ĭn-klo͞od′) *tr.v.* **-clud•ed, -clud•ing, -cludes 1.** To take in as a part, element, or member. **2.** To contain as a secondary or subordinate element. **3.** To consider with or place into a group, class, or total: *thanked the host for including us.* [Middle English *includen,* from Latin *inclūdere,* to enclose : *in-,* in; see IN–² + *claudere,* to close.] **—in•clud′a•ble, in•clud′i•ble** *adj.*

Synonyms *include, comprise, comprehend, embrace, involve* These verbs mean to take in or contain as part of something larger. *Include* often implies an incomplete listing: *"Through the process of amendment, interpretation and court decision I have finally been included in 'We, the people'"* (Barbara C. Jordan). *Comprise* usually implies that all of the components are stated: *The book comprises 15 chapters. Comprehend* and *embrace* usually refer to the taking in of subordinate elements: *My field of study comprehends several disciplines. This theory embraces many facets of human behavior. Involve* usually suggests inclusion as a logical consequence or necessary condition: *"Every argument involves some assumptions"* (Brooke F. Westcott).

Usage Note Some writers insist that *include* be used only when it is followed by a partial list of the contents of the referent of the subject. Therefore, one may write *New England includes Connecticut and Rhode Island,* but one must use *comprise* or *consist of* to provide full enumeration: *New England comprises* (not *includes*) *Connecticut, Rhode Island, Massachusetts, Vermont, New Hampshire, and Maine.* This restriction is too strong. *Include* does not rule out the possibility of a complete listing. Thus the sentence *The bibliography should include all the journal articles you have used* does not entail that the bibliography must contain something other than journal articles, though it does leave that possibility open. The use of *comprise* or *consist of,* however, will avoid ambiguity when a listing is meant to be exhaustive. Thus the sentence *The task force includes all of the Navy units on active duty in the region* allows for the possibility that Marine and Army units are also taking part, where the same sentence with *comprise* would entail that the task force contained only Navy forces. See Usage Note at **comprise.**

in•clud•ed (ĭn-klo͞o′dĭd) *adj.* **1.** *Botany* Not protruding beyond a surrounding part, as stamens that do not project from a corolla. **2.** *Mathematics* Formed by and between two intersecting straight lines: *an included angle.*

in•clu•sion (ĭn-klo͞o′zhən) *n.* **1.** The act of including or the state of being included. **2.** Something included. **3.** *Geology* A solid, liquid, or gaseous foreign body enclosed in a mineral or rock. **4.** *Biology* A nonliving mass, such as a droplet of fat, in the cytoplasm of a cell. **5.** *Computer Science* A logical operation that assumes the second statement of a pair is true if the first one is true. [Latin *inclūsiō, inclūsiōn-,* from *inclūsus,* past participle of *inclūdere,* to enclose. See INCLUDE.] **—in•clu′sion•ar′y** (-zhə-nĕr′ē) *adj.*

inclusion body *n.* An abnormal structure in a cell nucleus or cytoplasm having characteristic staining properties and associated especially with certain viral infections, such as rabies and smallpox.

in•clu•sive (ĭn-klo͞o′sĭv) *adj.* **1.** Taking a great deal or everything within its scope; comprehensive: *an inclusive survey of world economic affairs.* **2.** Including the specified extremes or limits as well as the area between them: *the numbers one to ten, inclusive.* **3.** *Linguistics* Of, relating to, or being a first person plural pronoun that includes the addressee, such as *we* in the sentence *If you're hungry, we could order some pizza.* **—in•clu′sive•ly** *adv.* **—in•clu′sive•ness** *n.*

inclusive of *prep.* Taking into consideration or account; including.

in•co•er•ci•ble (ĭn′kō-ûr′sə-bəl) *adj.* Difficult or impossible to coerce or control forcibly: *incoercible rebel leaders.*

in•cog•i•tant (ĭn-kŏj′ĭ-tənt) *adj.* Thoughtless; inconsiderate. [Latin *incōgitāns, incōgitant-* : *in-,* not; see IN–¹ + *cōgitāns,* present participle of *cōgitāre,* to think; see COGITATE.]

in•cog•ni•ta (ĭn′kŏg-nē′tə, ĭn-kŏg′nĭ-tə) *adv. & adj.* With one's identity disguised or concealed. Used of a woman. ❖ *n.* A woman or girl whose identity is disguised or concealed. [Italian, feminine of *incognito,* incognito. See INCOGNITO.]

in•cog•ni•to (ĭn′kŏg-nē′tō, ĭn-kŏg′nĭ-tō′) *adv. & adj.* With one's identity disguised or concealed. ❖ *n., pl.* **-tos 1.** One whose identity is disguised or concealed. **2.** The condition of having a disguised or concealed identity. [Italian, from Latin *incognitus,* unknown : *in-,* not; see IN–¹ + *cognitus,* past participle of *cognōscere,* to learn, recognize; see COGNITION.]

in•cog•ni•zant (ĭn-kŏg′nĭ-zənt) *adj.* Lacking knowledge or awareness; unaware: *incognizant of the new political situation.* **—in•cog′ni•zance** (-zəns) *n.*

in•co•her•ence (ĭn′kō-hîr′əns) *n.* **1.** The condition or quality of being incoherent. **2.** Something incoherent.

in•co•her•en•cy (ĭn′kō-hîr′ən-sē) *n., pl.* **-cies** Incoherence.

in•co•her•ent (ĭn′kō-hîr′ənt) *adj.* **1.** Lacking cohesion, connection, or harmony; not coherent: *incoherent fragments of a story.* **2.** Unable to think or express one's thoughts in a clear or orderly manner: *incoherent with grief.* **—in′co•her′ent•ly** *adv.* **—in′co•her′ent•ness** *n.*

in•com•bus•ti•ble (ĭn′kəm-bŭs′tə-bəl) *adj.* Incapable of burning. ❖ *n.* An incombustible object or material. **—in′com•bus′ti•bil′i•ty** *n.* **—in′com•bus′ti•bly** *adv.*

in•come (ĭn′kŭm′) *n.* **1.** The amount of money or its equivalent received during a period of time in exchange for labor or services, from the sale of goods or property, or as profit from financial investments. **2.** The act of coming in; entrance. [Middle English, arrival, entrance, from *incomen,* to come in, from Old English *incuman* : *in,* in; see IN¹ + *cuman,* to come; see COME.]

income bond *n.* A long-term debt security in which the issuer is required to pay interest only when interest is earned.

income fund *n.* An investment company whose main objective is to achieve current income for its owners.

income property *n.* Real estate that produces current income, typically from rental payments.

income tax *n.* A tax levied on net personal or business income.

income tax return *n.* See **return** (sense 16).

in•com•ing (ĭn′kŭm′ĭng) *adj.* **1.** Coming in or about to come in: *incoming trains; incoming mail; incoming mortar fire.* **2.** About to assume an office or position: *the incoming governor.* ❖ *n.* **1.** The act of coming in; arrival. **2.** Income; revenue. Often used in the plural.

in•com•men•su•ra•ble (ĭn′kə-mĕn′sər-ə-bəl, -shər-) *adj.* **1a.** Impossible to measure or compare. **b.** Lacking a common quality on which to make a comparison. **2.** *Mathematics* **a.** Having no common measure or number of which all the given lengths or measures are integral multiples. **b.** Having an irrational ratio. ❖ *n.* One that is incommensurable. **—in′com•men′su•ra•bil′i•ty** *n.* **—in′com•men′su•ra•bly** *adv.*

in•com•men•su•rate (ĭn′kə-mĕn′sər-ĭt, -shər-) *adj.* **1a.** Not commensurate; disproportionate: *a reward incommensurate with their efforts.* **b.** Inadequate. **2.** Incommensurable. **—in′com•men′su•rate•ly** *adv.* **—in′com•men′su•rate•ness** *n.*

in•com•mode (ĭn′kə-mōd′) *tr.v.* **-mod•ed, -mod•ing, -modes** To cause to be inconvenienced; disturb. [French *incommoder,* from Old French, from Latin *incommodāre,* from *incommodus,* inconvenient : *in-,* not; see IN–¹ + *commodus,* convenient; see COMMODIOUS.]

in•com•mo•di•ous (ĭn′kə-mō′dē-əs) *adj.* Inconvenient or uncomfortable, as by not affording sufficient space. **—in′com•mo′di•ous•ly** *adv.* **—in′com•mo′di•ous•ness** *n.*

in•com•mod•i•ty (ĭn′kə-mŏd′ĭ-tē) *n., pl.* **-ties 1.** Inconvenience. **2.** Something inconvenient.

in•com•mu•ni•ca•ble (ĭn′kə-myo͞o′nĭ-kə-bəl) *adj.* **1.** Impossible to be transmitted; not communicable: *an incommunicable disease.* **2.** Incommunicative: *an executive who was maddeningly incommunicable.* **—in′com•mu′ni•ca•bil′i•ty** *n.* **—in′com•mu′ni•ca•bly** *adv.*

in•com•mu•ni•ca•do (ĭn′kə-myo͞o′nĭ-kä′dō) *adv. & adj.* Without the means or right of communicating with others: *a prisoner held incommunicado; incommunicado political detainees.* [Spanish *incomunicado,* past participle of *incomunicar,* to deny communication : *in-,* not (from Latin; see IN–¹) + *comunicar,* to communicate (from Latin *commūnicāre;* see COMMUNICATE).]

in•com•mu•ni•ca•tive (ĭn′kə-myo͞o′nĭ-kə-tĭv, -kā′tĭv) *adj.* Not disposed to be forthcoming or communicative; uncommunicative: *an incommunicative press secretary.* **—in′com•mu′ni•ca•tive•ly** *adv.* **—in′com•mu′ni•ca•tive•ness** *n.*

in•com•mut•a•ble (ĭn′kə-myo͞o′tə-bəl) *adj.* **1.** Not able to be exchanged one for another: *a rare, incommutable skill.* **2.** That cannot be altered: *an incommutable death sentence.* **—in′com•mut′a•bil′i•ty, in′com•mut′a•ble•ness** *n.* **—in′com•mut′a•bly** *adv.*

in•com•pa•ra•ble (ĭn-kŏm′pər-ə-bəl) *adj.* **1.** Being such that comparison is impossible; incommensurable. **2.** So outstanding as to be beyond comparison; unsurpassed. **—in•com′pa•ra•bil′i•ty, in•com′pa•ra•ble•ness** *n.* **—in•com′pa•ra•bly** *adv.*

in•com•pat•i•bil•i•ty (ĭn′kəm-păt′ə-bĭl′ĭ-tē) *n., pl.* **-ties 1.** The state or quality of being incompatible. **2. incompatibilities** Mutually exclusive or antagonistic qualities or things.

in•com•pat•i•ble (ĭn′kəm-păt′ə-bəl) *adj.* **1.** Incapable of associating or blending or of being associated or blended because of disharmony, incongruity, or antagonism: *incompatible perspectives on religion.* **2.** Impossible to be held simultaneously by one person: *the incompatible offices of prosecutor and judge.* **3.** *Logic* That cannot be simultaneously true; mutually exclusive. **4.** *Medicine* **a.** Producing an undesirable effect when used in combination with a particular substance: *a medication that is incompatible with alcohol.* **b.** Not immunologically compatible: *incompatible blood types.* ❖ *n.* One that is incompatible. **—in′com•pat′i•ble•ness** *n.* **—in′com•pat′i•bly** *adv.*

in•com•pe•tence (ĭn-kŏm′pĭ-təns) *n.* The quality or state of being incompetent.

in•com•pe•ten•cy (ĭn-kŏm′pĭ-tən-sē) *n., pl.* **-cies** Incompetence.

in•com•pe•tent (ĭn-kŏm′pĭ-tənt) *adj.* **1.** Not qualified in legal terms: *a defendant who was incompetent to stand trial.* **2.** Inadequate for or unsuited to a particular purpose or application. **3.** Devoid of those qualities requisite for effective conduct or action. ❖ *n.* An incompetent person. **—in•com′pe•tent•ly** *adv.*

in•com•plete (ĭn′kəm-plēt′) *adj.* **1.** Not complete. **2.** *Football* Not caught in bounds or intercepted: *an incomplete forward pass.* **—in′com•plete′ly** *adv.* **—in′com•plete′ness, in′com•ple′tion** *n.*

incomplete abortion *n.* An induced abortion in which the contents of the uterus are not completely expelled.

incomplete dominance *n.* A heterozygous condition in which both alleles at a gene locus are partially expressed, often producing an intermediate phenotype.

incomplete flower *n.* A flower lacking sepals, petals, stamens, or pistils.

incomplete fracture *n.* A fracture that does not extend through the full transverse width of a bone.

incomplete metamorphosis *n.* A life cycle of certain insects, such as crickets and grasshoppers, characterized by the absence of a pupal stage between the immature and adult stages.

in•com•pli•ant (ĭn′kəm-plī′ənt) *adj.* Not willing to comply; un-

ă pat	oi boy
ā pay	ou out
âr care	o͝o took
ä father	o͞o boot
ĕ pet	ŭ cut
ē be	ûr urge
ĭ pit	th thin
ī pie	*th* this
îr pier	hw which
ŏ pot	zh vision
ō toe	ə about, item
ô paw	♦ regionalism

Stress marks: **′** (primary); ′ (secondary), as in **dictionary** (dĭk′shə-nĕr′ē)

EXHIBIT 5

American Heritage Dictionary

into thoughtless bickering. —**thought′less•ly** *adv.* —**thought′less•ness** *n.*

thought reading *n.* Mind reading.

thou•sand (thou′zənd) *n.* The cardinal number equal to 10 × 100 or 10^3. [Middle English, from Old English *thūsend.* See **teuə-** in Appendix I.] —**thou′sand** *adj. & pron.*

Thou•sand Island dressing (thou′zənd) *n.* A salad dressing made with mayonnaise, chili sauce, and seasonings. [Perhaps after the THOUSAND ISLANDS.]

Thousand Islands A group of more than 1,800 islands of northern New York and southeast Ontario, Canada, in the St. Lawrence River at the outlet of Lake Ontario. The islands, some of which are privately owned, are a popular resort area.

Thousand Oaks A city of southern California west of Los Angeles. Mainly residential, it has some light industry. Population: 104,352.

thou•sandth (thou′zəndth, -zənth) *n.* **1.** The ordinal number matching the number 1,000 in a series. **2.** One of 1,000 equal parts. —**thou′sandth** *adv. & adj.*

thp also **t.hp.** *abbr.* thrust horsepower

Thrace (thrās) A region and ancient country of the southeast Balkan Peninsula north of the Aegean Sea. In ancient times it extended as far north as the Danube River. The region was colonized by Greeks in the seventh century B.C. and later passed under the control of Rome, Byzantium, and Ottoman Turkey. Northern Thrace was annexed by Bulgaria in 1885, and eastern Thrace passed to Turkey in 1923.

Thra•cian (thrā′shən) *adj.* Of or relating to Thrace or its people. ❖ *n.* **1.** A native or inhabitant of Thrace. **2.** The Indo-European language of the ancient Thracians.

Thrale (thrāl), Mrs. See Hester Lynch **Piozzi.**

thrall (thrôl) *n.* **1a.** One, such as a slave or serf, who is held in bondage. **b.** One who is intellectually or morally enslaved. **2.** Servitude; bondage: *"a people in thrall to the miracles of commerce"* (Lewis H. Lapham). ❖ *tr.v.* **thralled, thrall•ing, thralls** *Archaic* To enslave. [Middle English, from Old English *thrǣl,* from Old Norse *thrǣll.*] —**thrall′dom, thral′dom** *n.*

thrash (thrăsh) *v.* **thrashed, thrash•ing, thrash•es** —*tr.* **1.** To beat with or as if with a flail, especially as a punishment. See synonyms at **beat. 2.** To swing or strike in a manner suggesting the action of a flail: *The alligator thrashed its tail.* **3.** To defeat utterly; vanquish. **4.** To thresh. **5.** To sail (a boat) against opposing winds or tides. —*intr.* **1.** To move wildly or violently: *thrashed about all night.* **2.** To strike or flail. **3.** To thresh. **4.** To sail against opposing tides or winds. ❖ *n.* **1.** The act or an instance of thrashing. **2.** *Music* See **speed metal.** —***phrasal verb:* thrash out** To discuss fully. [Variant of THRESH.] —**thrash′er** *n.*

thrash•er (thrăsh′ər) *n.* Any of various New World songbirds of the genus *Toxostoma,* related to the mockingbird and having a long tail, a long curved beak, and usually a brown head and back. [Perhaps alteration of THRUSH[1].]

thrash•ing (thrăsh′ĭng) *n.* A severe beating.

thra•son•i•cal (thră-sŏn′ĭ-kəl, thrə-) *adj.* Boastful. [After *Thrasō,* a character in the play *Eunuchus* by Terence.] —**thra•son′i•cal•ly** *adv.*

Thras•y•bu•lus (thrăs′ə-byo͞o′ləs) Died c. 389 B.C. Athenian military and political leader who led the overthrow (403) of the tyrannical oligarchy established by Sparta in Athens.

thrawn (thrôn) *adj. Chiefly Scots* **1.** Crooked or twisted; misshapen. **2.** Perverse; contrary. [Scots, past participle of *thraw,* to twist, wrench, from Middle English *thrauen,* from Old English *thrāwan.* See THROW.] —**thrawn′ly** *adv.*

thread (thrĕd) *n.* **1a.** Fine cord of a fibrous material, such as cotton or flax, made of two or more filaments twisted together and used in needlework and the weaving of cloth. **b.** A piece of such cord. **2a.** A thin strand, cord, or filament of natural or manufactured material. **b.** Something that suggests the fineness or thinness of such a strand, cord, or filament: *a thread of smoke.* **c.** Something that suggests the continuousness of such a strand, cord, or filament: *lost the thread of his argument.* **3.** A helical or spiral ridge on a screw, nut, or bolt. **4.** *Computer Science* **a.** A portion of a program that can run independently of and concurrently with other portions of the program. **b.** A set of posts on a newsgroup, composed of an initial post about a topic and all responses to it. **5. threads** *Slang* Clothes. ❖ *v.* **thread•ed, thread•ing, threads** —*tr.* **1a.** To pass one end of a thread through the eye of (a needle, for example). **b.** To pass (something) through in the manner of a thread: *thread the wire through the opening.* **c.** To pass a tape or film into or through (a device): *thread a film projector.* **d.** To pass (a tape or film) into or through a device. **2.** To connect by running a thread through; string: *thread beads.* **3a.** To make one's way cautiously through: *threading dark alleys of the city.* **b.** To make (one's way) cautiously through something. **4.** To occur here and there throughout; pervade: *"More than 90 geologic faults thread the Los Angeles area"* (Science News). **5.** To machine a thread on (a screw, nut, or bolt). —*intr.* **1.** To make one's way cautiously: *threaded through the shoals and sandbars.* **2.** To proceed by a winding course. **3.** To form a thread when dropped from a spoon, as boiling sugar syrup. [Middle English, from Old English *thrǣd.* See **terə-**[1] in Appendix I.] —**thread′er** *n.*

thread•bare (thrĕd′bâr′) *adj.* **1.** Having the nap worn down so that the filling or warp threads show through; frayed or shabby: *threadbare rugs.* **2.** Wearing old, shabby clothing. **3.** Overused to the point of being worn out; hackneyed: *threadbare excuses.*

thread•fin (thrĕd′fĭn′) *n., pl.* **threadfin** or **-fins** Any of various chiefly tropical marine fishes of the family Polynemidae, having threadlike rays extending from the lower part of the pectoral fin.

thread•worm (thrĕd′wûrm′) *n.* See **pinworm.**

thread•y (thrĕd′ē) *adj.* **-i•er, -i•est 1.** Consisting of or resembling thread; filamentous. **2.** Capable of forming or tending to form threads; viscid. **3.** *Medicine* Weak and shallow. Used of a pulse. **4.** Lacking fullness of tone; thin: *a thready voice.* —**thread′i•ness** *n.*

threat (thrĕt) *n.* **1.** An expression of an intention to inflict pain, injury, evil, or punishment. **2.** An indication of impending danger or harm. **3.** One that is regarded as a possible danger; a menace. ❖ *tr.v.* **threat•ed, threat•ing, threats** *Archaic* To threaten. [Middle English, from Old English *thrēat,* oppression. See **treud-** in Appendix I.]

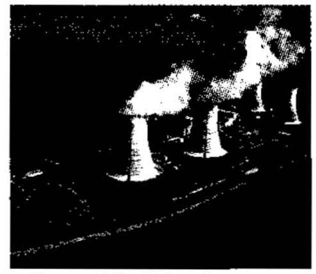
threat•en (thrĕt′n) *v.* **-ened, -en•ing, -ens** —*tr.* **1.** To express a threat against. **2.** To be a source of danger to; menace. **3.** To give signs or warning of; portend. **4.** To announce the possibility of in a threat. —*intr.* **1.** To express or use threats. **2.** To indicate danger or harm. —**threat′en•er** *n.* —**threat′en•ing•ly** *adv.*

threat•ened (thrĕt′nd) *adj. Ecology* At risk of becoming endangered. Used of a plant or an animal.

three (thrē) *n.* **1.** The cardinal number equal to 2 + 1. **2.** The third in a set or sequence. **3.** Something having three parts, units, or members. [Middle English, from Old English *thrī.* See **trei-** in Appendix I.] —**three** *adj. & pron.*

Three Age system (thrē) *n.* A system for classifying prehistoric artifacts according to successive stages of technological development, divided into the Stone, Bronze, and Iron ages.

Usage Note In organizing the extensive collection of artifacts at the National Museum of Denmark, the 19th-century Danish archaeologist Christian Thomsen proposed an innovative system based on the assumption of a progression in human technology from stone to bronze to iron. His insight that early technology had developed in chronological stages rather than concurrently at different levels of society proved essentially correct, though ultimately of limited use in describing the various progressions in other parts of the world. Once empirical study of archaeological collections began, Thomsen's Three Age system was rapidly modified into four ages by the subdivision of the Stone Age into the Old Stone (now Paleolithic) and New Stone (Neolithic) ages. Subsequent refinement has added Mesolithic (Middle Stone) and Chalcolithic (Copper and Stone) to the original terms, which are now known as periods rather than ages. Use of the full terminology—Paleolithic, Mesolithic, Neolithic, Chalcolithic, Bronze, and Iron—is appropriate only for Europe, the Middle East, and Egypt, and even there it is not uniformly accepted among archaeologists today.



Three Mile Island
aerial view of Three Mile Island nuclear power plant

three-bag•ger (thrē′băg′ər) *n.* See **three-base hit.**

three-base hit (thrē′bās′) *n. Baseball* A base hit that allows the batter to reach third base without being put out. Also called *three-bagger, triple.*

three-card monte (thrē′kärd) *n.* A gambling game in which the dealer shows a player three cards, then turns them face down and moves them around, and the player must guess the position of a particular card.

three-col•or (thrē′kŭl′ər) *adj.* Of, relating to, or being a color printing or photographic process in which three primary colors are transferred by three different plates or filters to a surface, reproducing all the colors of the subject matter.

3-D or **3D** also **three-D** (thrē′dē′) *adj.* Three-dimensional. ❖ *n.* A three-dimensional medium, display, or performance, especially a cinematic or graphic medium in three dimensions: *They shot the movie in 3-D.*

three-deck•er (thrē′dĕk′ər) *n.* **1.** A ship having three decks, especially one of a class of sail-powered warships with guns on three decks. **2.** Something with three levels or layers, as: **a.** A three-story apartment building. **b.** A sandwich having three slices of bread.

three-di•men•sion•al (thrē′dĭ-mĕn′shə-nəl, -dī-) *adj.* **1.** Of, relating to, having, or existing in three dimensions. **2.** Having or appearing to have extension in depth. **3.** Treating many aspects of a subject; lifelike: *a three-dimensional account of conditions under the new government.*

three-piece
three-piece suit

three-gait•ed (thrē′gā′tĭd) *adj.* Trained in the walk, trot, and canter. Used of a horse.

three-leg•ged race (thrē′lĕg′ĭd, -lĕgd′) *n.* A race in which contestants run in pairs with their near legs tied together.

Three Mile Island An island in the Susquehanna River in southeast Pennsylvania southeast of Harrisburg. It was the site of a major nuclear accident on March 28, 1979, when a partial meltdown released radioactive material and forced the evacuation of thousands of nearby residents.

three-mile limit (thrē′mīl′) *n. Law* The outer limit of the area extending three miles out to sea from the coast of a country, sometimes considered to constitute the country's territorial waters.

three•pence (thrĕp′əns, thrĭp′-, thrŭp′-) *n., pl.* **threepence** or **-penc•es 1.** A coin worth three pennies, formerly used in Great Britain. **2.** The sum of three pennies.

three•pen•ny (thrĕp′ə-nē, thrĭp′-, thrŭp′-) *adj.* **1.** Worth or priced at threepence. **2.** Very small; trifling.

three-piece (thrē′pēs′) *adj.* Made in or consisting of three parts or pieces, as a suit consisting of a jacket, trousers, and a vest.

three-ply (thrē′plī′) *adj.* Consisting of three layers or strands.

three-point landing (thrē′point′) *n.* An airplane landing in which the two main wheels and the nose wheel, tail wheel, or tailskid all touch the ground simultaneously.

three-quar•ter (thrē′kwôr′tər) *adj.* **1.** Relating to, consisting of, or extending to three fourths of the usual full length: *a skirt of three-quarter length.* **2.** Depicting the subject turned slightly from a full frontal view: *a three-quarter portrait.*

ă pat	oi boy
ā pay	ou out
âr care	o͝o took
ä father	o͞o boot
ĕ pet	ŭ cut
ē be	ûr urge
ĭ pit	th thin
ī pie	*th* this
îr pier	hw which
ŏ pot	zh vision
ō toe	ə about, item
ô paw	♦ regionalism

Stress marks: **′** (primary); ′ (secondary), as in **dictionary** (dĭk′shə-nĕr′ē)

EXHIBIT 5

American Heritage Dictionary

Quantum Dot Heterostructures

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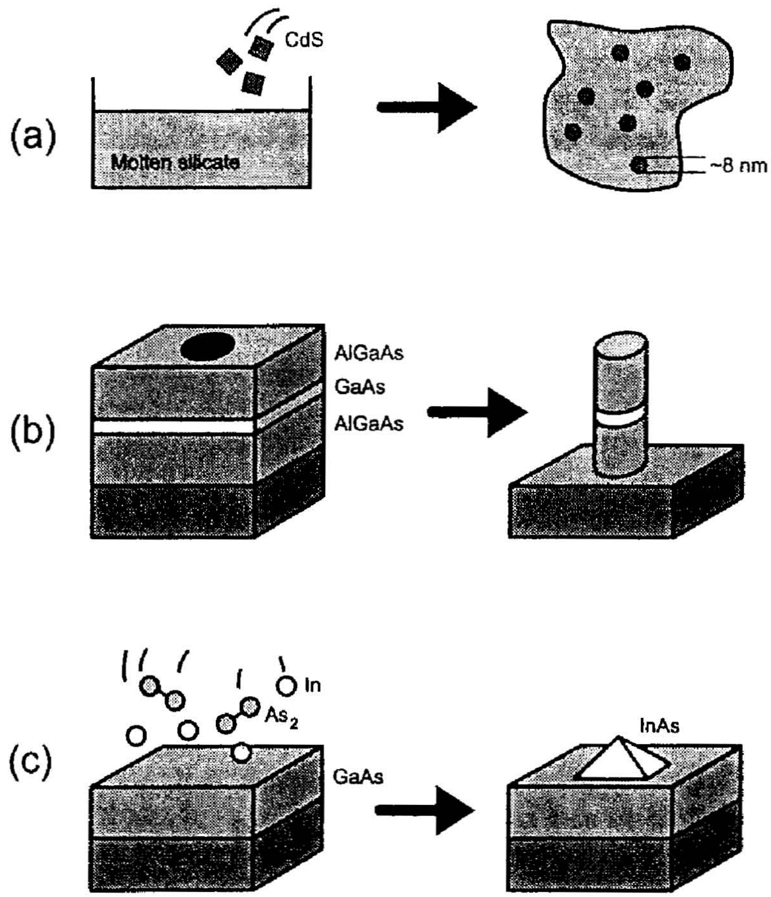

Fig. 1.3 Schematic representation of different approaches to fabrication of nanostructures: (a) microcrystallites in glass, (b) artificial patterning of thin film structures, (c) self-organized growth of nanostructures

stage. The electrically isolating matrix, however, prohibits electric injection and use in electronic and optoelectronic devices. Many alternative approaches have been developed, one of them being artificial patterning of thin layer structures into three-dimensional regions (Fig. 1.3b).

In the last few years nanostructures have been successfully realized using self-organization effects, e.g. occurring during growth of strained heterostructures (Fig. 1.3c). These effects are also called self-ordering or self-assembly. Both thermodynamic and kinetic ordering mechanisms together can create unique three-dimensional patterns of islands within a matrix for many different material systems. The word 'self-organization' in other fields of science, in particular biology, is used for systems away from equilibrium. In contrast, QD formation is in many cases an equilibrium process.

The self-organization effects discussed in this book are a general phenomenon of strained heterosystems. The fabrication process of such quantum dots is compatible with present optoelectronic device technology. A beautiful and well-understood model system for which many examples of results will be presented is InGaAs/AlGaAs. This material combination appears at the moment to be the most promising candidate for immediate device applications. Exciting reports on

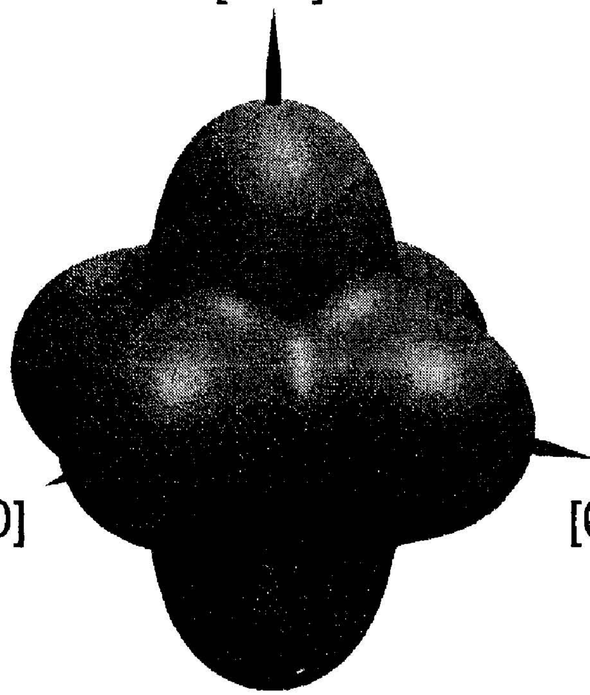

Fig. 3.8 $1/Y$, Y being Young's modulus for different directions in GaAs, visualizing the anisotropy of elastic properties in zincblende crystals

concentration has been established by Zeppenfeld *et al.* (1994). In the particular case of monolayer-height islands, this result means that there exists an optimum island size for a dilute array of islands. The existence of an optimum size of islands implies that two-dimensional strained islands in the heterophase system do not undergo Ostwald (1900) ripening.

Similar results are valid for a dilute array of strained islands of macroscopic height for the case where islands have a planar top surface, and the height of the islands is *kinetically limited* to a value considerably smaller than the lateral size (Tersoff *et al.*, 1993). The global geometry of such islands is similar to the geometry of two-dimensional islands. The important result is that there exists an optimum size in a system of planar strained islands and no Ostwald ripening occurs.

3.6 ORDERED ARRAYS OF THREE-DIMENSIONAL COHERENTLY STRAINED ISLANDS

3.6.1 HETEROEPITAXIAL GROWTH IN LATTICE-MISMATCHED SYSTEMS

There are three well-known modes of heteroepitaxial growth: Frank–van der Merwe (1949), Volmer–Weber (1926) and Stranski–Krastanow (1937). They represent layer-by-layer growth (FvdM, 2D), island growth (VW, 3D), and layer-by-layer

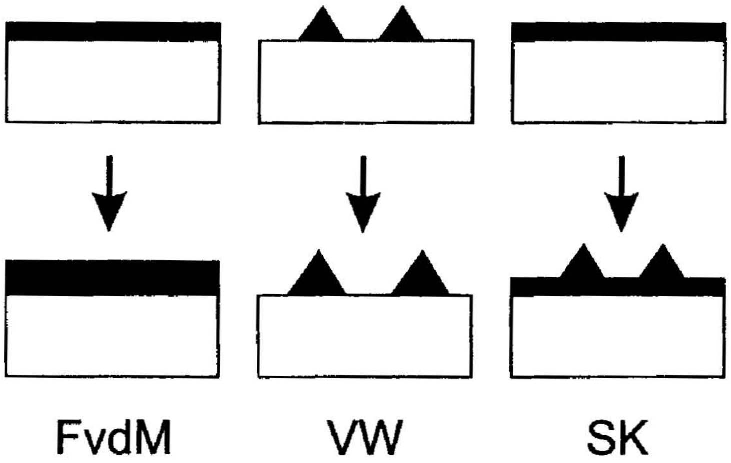

Fig. 3.9 Schematic diagrams of the three possible growth modes: Frank–van der Merwe (FvdM), Volmer–Weber (VW), and Stranski–Krastanow (SK)

plus islands (SK) (Fig. 3.9). The particular growth mode for a given system depends on the interface energies and on the lattice mismatch.

In lattice-matched systems, the growth mode is solely governed by the interface and surface energies. If the sum of the epilayer surface energy γ_2 and of the interface energy γ_{12} is lower than the energy of the substrate surface, $\gamma_2 + \gamma_{12} < \gamma_1$, i.e. if the deposited material *wets* the substrate, the FvdM mode occurs. A change in $\gamma_2 + \gamma_{12}$ alone may drive a transition from the FvdM to the VW growth mode. For a strained epilayer with small interface energy, initial growth may occur layer by layer, but a thicker layer has a large strain energy and can lower its energy by forming isolated islands in which strain is relaxed. Thus the SK growth mode occurs. It was traditionally believed that islands formed in the SK growth mode are dislocated. However, experiments on InAs/GaAs (001) (Goldstein *et al.*, 1985) and on Ge/Si(001) (Eaglesham and Cerullo, 1990; Mo *et al.*, 1990) have demonstrated the formation of three-dimensional *coherently* strained islands.

The relaxation of the elastic energy due to the formation of coherently strained islands is related to the Asaro–Tiller–Grinfield instability (Asaro and Tiller, 1972; Grinfield, 1986; Srolovitz, 1989; Spencer *et al.*, 1991) of a strained layer against a long-wavelength corrugation of the surface. To illustrate the physical mechanism of the elastic relaxation, it is convenient to consider a strongly pronounced corrugation. Among examples of such strongly pronounced corrugations are islands (Vanderbilt and Wickham, 1991), troughs (Vanderbilt and Wickham, 1991), surface cusps (Jesson *et al.*, 1993) and cracks (Yang and Srolovitz, 1993). The formation of troughs, cusps, and cracks can occur in a strained epitaxial film of a certain macroscopic thickness under annealing. For the first stages of heteroepitaxial growth on a substrate, the formation of islands seems to be the only coherent mechanism of elastic relaxation.

Figure 3.10 demonstrates two islands of a different shape. A flat island with a small height/width ratio is practically nonrelaxed, whereas a hypothetical island

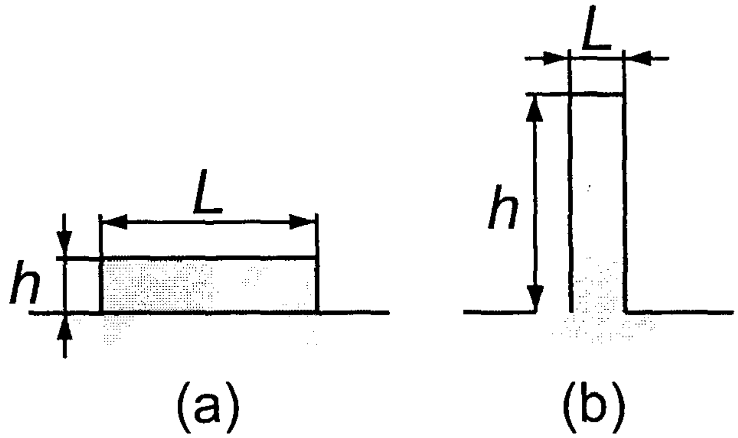

Fig. 3.10 Effect of the island shape on the volume elastic relaxation of a coherently strained island. The grey area represents the part with a large strain energy density. (a) The island with a height/width ratio $h/L \ll 1$ is not relaxed, while (b) the island with a height/width ratio $h/L \gg 1$ is almost completely relaxed

having the shape of a whisker with a large height/width ratio is almost completely relaxed. Thus the elastic relaxation depends strongly on the island shape. For a given shape, the elastic relaxation energy is proportional to the volume of the island.

Thus the volume elastic relaxation of coherently strained islands is an alternative mechanism of relaxation which competes with the formation of dislocations. The theory developed by Vanderbilt and Wickham (1991) compares the two mechanisms of elastic relaxation and yields a phase diagram of a lattice-mismatched system where all possible morphologies are present, i.e. uniform films, dislocated islands, and coherent islands (Fig. 3.11). The formation of an island from a uniform film is accompanied by a relaxation of the elastic energy, $\Delta E^{V}_{\text{elastic}} < 0$, and by a change of the surface area, $\Delta A < 0$. The size of the corresponding change of the surface energy depends on the formation of side facets of the islands and on the disappearance of certain areas of the planar surface. It is usually believed that the change of the surface energy caused by the formation of islands is *positive*, $\Delta E_{\text{surf}} > 0$. It was shown by Vanderbilt and Wickham (1991) that the morphology of the mismatched system is determined by the relation between ΔE_{surf} and the energy of the dislocated interface $E^{\text{disl}}_{\text{interf}}$. The ratio of these two energies, denoted $\Gamma = E^{\text{disl}}_{\text{interf}}/\Delta E_{\text{surf}}$, is the control parameter that governs the morphological phase diagram of Fig. 3.11.

If ΔE_{surf} is positive and large, or the energy of the dislocated interface is relatively small, the corresponding value Γ on the phase diagram of Fig. 3.11 is smaller than Γ_0. Then formation of coherently strained islands is not favorable. With the increase of the amount Q of the deposited material, a transition occurs from a uniform film to dislocated islands (or a dislocated film), and coherently strained islands are not formed.

If ΔE_{surf} is positive and small, or the energy of the dislocated interface is relatively large, the corresponding value Γ on the phase diagram of Fig. 3.11 is larger than Γ_0.

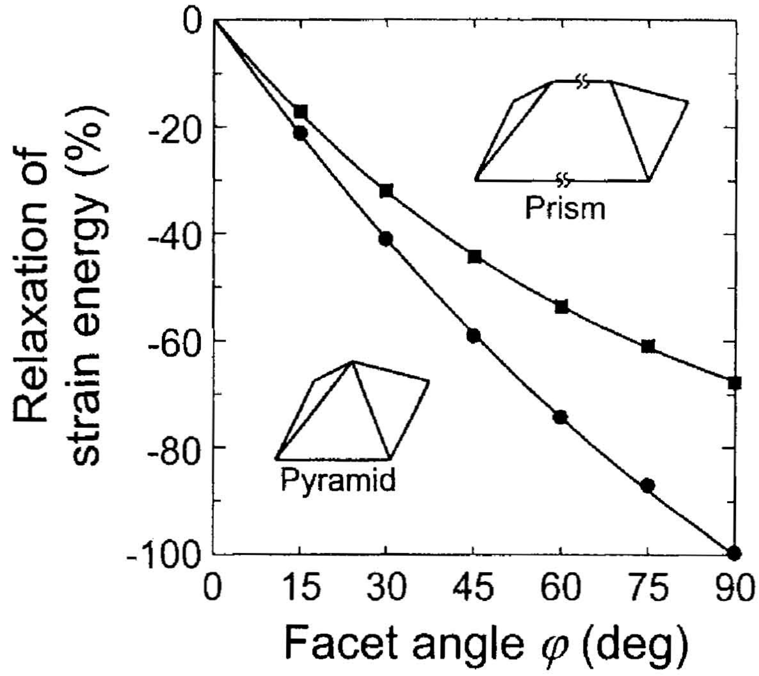

Fig. 3.12 Relaxation of elastic strain energy for 3D coherently strained islands versus the tilt angle of island facets for pyramids (lower curve) and for elongated prisms (upper curve). Circles and squares represent results of calculations by the finite element method, which are fitted by the solid lines

3.6.3 ORDERING OF 3D ISLANDS IN SHAPE

For a dilute system of islands, where the average distance between the islands is large compared to the island size L, the equilibration of the island shape by atomic migration on the island is faster than material exchange between islands. Then for any given volume of an island, there exists an equilibrium shape. For sufficiently large islands, the first two terms in the island energy (Eq. 3.21), $\Delta\tilde{E}^{V}_{\text{elastic}}$ and $\Delta\tilde{E}^{\text{renorm}}_{\text{surf}}$, are the two dominant ones.

We focus on the situation here where the surface free energy of tilted facets of the deposited material per unit projected area, $\gamma_0(\hat{\mathbf{m}})(\hat{\mathbf{m}}\cdot\hat{\mathbf{n}})^{-1}$, has cusped local minima for four equivalent facets: $(k0l)$, $(0kl)$, $(\bar{k}0l)$, and $(0\bar{k}l)$. It yields cusped minima in $\Delta\tilde{E}^{\text{renorm}}_{\text{surf}}$ which fix the tilt angle of island facets for a certain interval of island volumes (or sizes). Then, we consider islands bounded by four facets with the same tilt angle relative to the substrate, i.e., by facets $(k0l)$, $(0kl)$, $(\bar{k}0l)$, and $(0\bar{k}l)$.

Comparison of pyramids and prisms is presented in Fig. 3.12 where the volume elastic relaxation energy versus the tilt angle of facets is displayed for a square-based pyramid and for an infinitely elongated prism. For the prism, the component of the strain field in the direction along the prism remains equal to ε_0 throughout the entire volume of the island, whereas for the pyramid, all components of the strain undergo relaxation and decrease with the height. Thus, Fig. 3.12 demonstrates that the volume elastic relaxation is more efficient for pyramids ('quantum dots') than for

Growth by molecular beam epitaxy and characterization of InAs/GaAs strained-layer superlattices

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InAs/GaAs superlattices with ultra-thin InAs (few monolayer) were grown on GaAs substrates. Nucleation of InAs occurs in a two-dimensional or a three-dimensional way depending on the growth conditions. The physical properties: x ray, transmission electron microscopy, and photoluminescence were used to characterize the different growth processes.

Strained-layer superlattices (SLS's) have original properties due to the combination of quantum size effect and strain. The InAs/GaAs system is very attractive because of the large gap difference ($\Delta E_g = 1.1$ eV).

Two kinds of nucleation have been identified when InAs is grown on a GaAs substrate, depending on growth conditions.[1–3] For ultra-thin InAs films a two-dimensional growth (2D) is observed.[1,4] When the layer thickness is increased, the strains in the epitaxial film induce a transition from the 2D to a three-dimensional growth (3D) with island formation under arsenic-rich conditions. This has been evidenced by reflection of high electron energy diffraction (RHEED) observations.[1]

The transition from 2D to 3D depends on the main growth parameters: substrate temperature, arsenic pressure, and film thickness. It is not clear yet if this transition occurs with dislocation formation. Also the physical properties of the InAs clusters in GaAs (3D phase) have not been studied so far.

In this letter we report on the growth conditions and the characterization of ultra-thin InAs on GaAs. Scanning transmission electron microscopy (STEM) and x-ray double diffraction have been used to characterize the two different nucleation processes. Also photoluminescence has been shown to be very sensitive to the formation of In-rich clusters.

Molecular beam epitaxy (MBE) was performed in a Riber 2300 system. The GaAs (100) substrates were etched in the standard H_2SO_4:H_2O_2:H_2O (5:1:1) solution and then rinsed in de-ionized water. The native oxide was removed by thermal desorption at 630 °C under As pressure. The growth rate of GaAs was maintained at 1 μm/h for the buffer layer as well as the various intermediate layers. The InAs growth rate, however, was reduced to 0.2 monolayer (0.2 ML) per

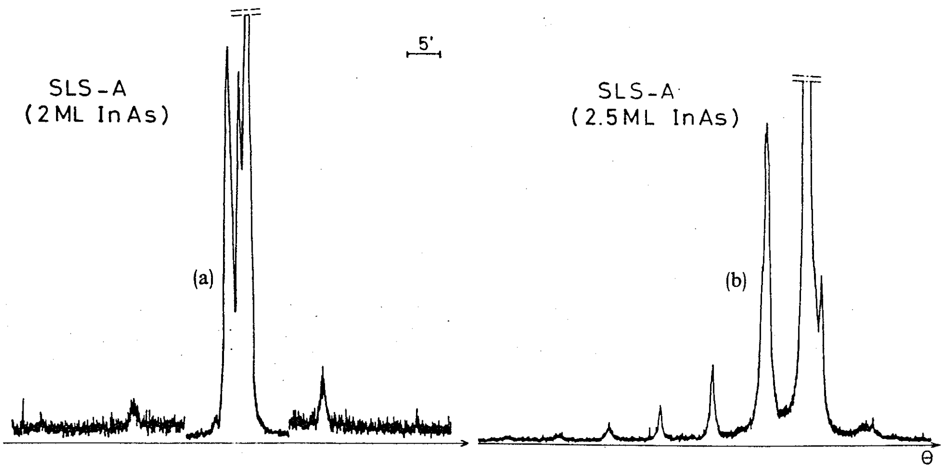

FIG. 1. X-ray spectra of SLS A, (a) with $L_w = 2$ ML of InAs and (b) with $L_w = 2.5$ ML of InAs.

second. This enables a better control of the InAs thickness in the range of a few monolayers. The substrate temperature was relatively high (550 °C) in order to optimize the optical quality of the films.[3] Desorption of In is low in this temperature range. The arsenic beam equivalent pressure was 2×10^{-5} Torr. This corresponds to an arsenic stabilized surface for both GaAs and InAs.

The RHEED pattern observed along the (110) direction exhibits two different aspects when InAs is deposited on top of a well-defined (2×4) reconstructed GaAs surface. For $0 < L_w < 2$ ML (where L_w is the InAs film thickness), the RHEED pattern becomes diffuse with disappearance of the main and reconstruction streaks. This probably indicates a disorder of atoms on the surface induced by the strain. For $L_w > 2$ ML we observed an abrupt transition from diffuse to spotty pattern. This corresponds to a 3D nucleation with island formation. This critical thickness (L_c) at which the nucleation changes from 2D to 3D depends on the growth parameters. We have observed that L_c decreases when the arsenic pressure is increased. This is consistent with previously reported results.[1]

When GaAs is deposited on top of InAs, the RHEED pattern recovers progressively to a sharp (2×4) reconstruction. This clearly indicates that the crystallinity of GaAs improves gradually starting from the InAs/GaAs interface. The recovery of smooth GaAs depends on the InAs thickness underneath. For $L_w = 2$ ML it takes 20–30 ML of GaAs to restore the RHEED (2×4) pattern.

Two different types of structure have been grown using these previous conditions. The simplest is an InAs/GaAs superlattice of 15 periods (SLS A). The GaAs sublayers were relatively thick (200–300 Å) in order to improve the crystallinity of the overall structure. L_w (InAs) was varied from 1 to 4 ML. For $L_w > 4$ ML the sample showed cross-hatched patterns with poor crystallinity.

In the second SLS system the barrier is also thick (200–300 Å), but the quantum well is designed in a different way (SLS B). It consists of a "digit" structure made with a finite number (two to six) of InAs ultra-thin layers with thickness < 1 ML, each one being separated by 10–15 Å of GaAs (inset Fig. 3). By using this procedure it is possible to obtain quantum wells with binary compound in a typical thickness range of 15–100 Å. Both structures have been grown in the 2D or 3D conditions.

The superlattices have been characterized by x-ray double diffraction. Figure 1 shows two spectra corresponding respectively to (a) SLS A with $L_w = 2$ ML (2D nucleation) and (b) SLS A with 2.5 ML (3D nucleation). An x-ray diffraction calculation of SLS[5] shows that the spectra consist of two sets of peaks. The maximum of each envelope corresponds to the angular position of the lattice parameter of the two mate-

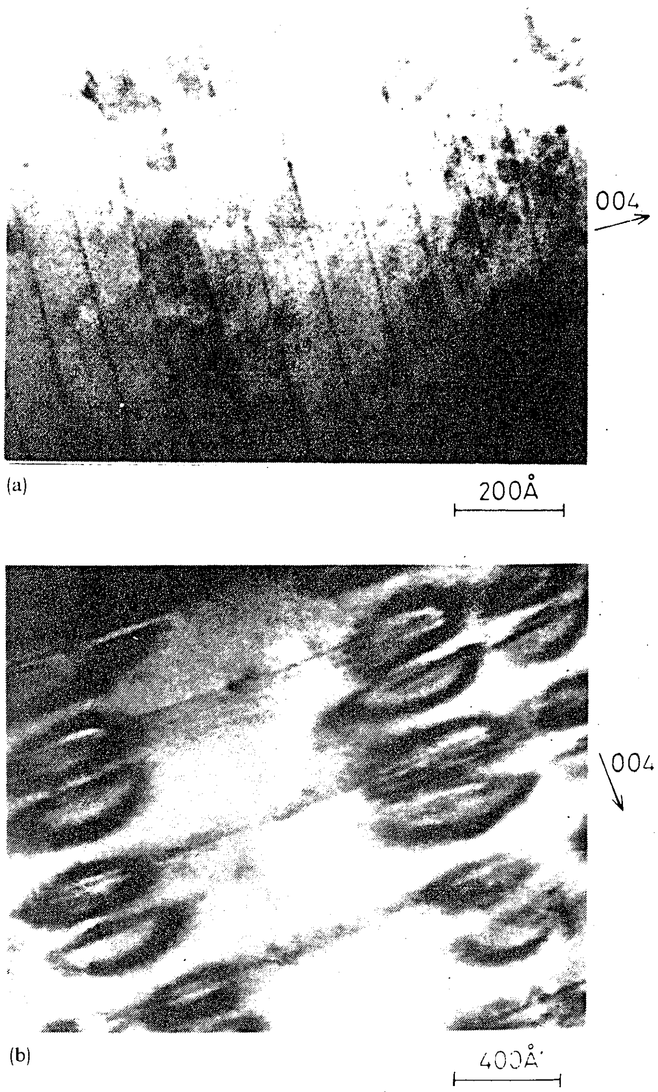

FIG. 2. STEM micrographs (a) SLA A with 2 ML and (b) SLS B with 2.5 ML.

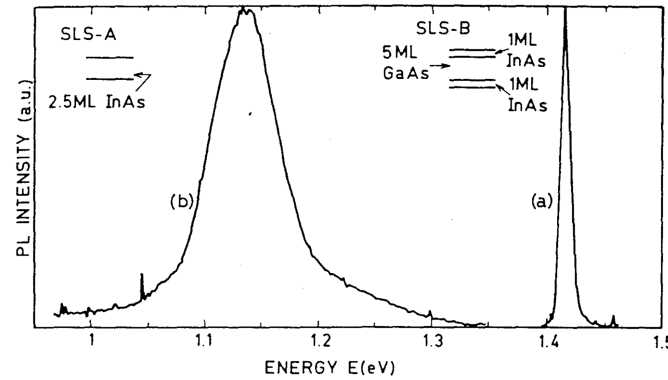

FIG. 3. Photoluminescence at 77 K for (a) 2D and (b) 3D.

rials. For $L_b \gg L_w$ (L_b = GaAs width) only the peaks corresponding to GaAs give rise to x-ray spectra. In the case of 2D nucleation [Fig. 1(a)] the envelope is centered on the GaAs substrate. However, for 3D nucleation [Fig. 1(b)] the maximum is moved towards lower angles. The progressive change in the GaAs crystallinity from a disturbed (top of InAs) to a smooth surface induces this shift. The average lattice parameter in the growth direction of the GaAs in the smoothing layer is greater than that in the GaAs substrate ($\Delta a/a = 0.4\%$). However, a precise fit of the spectra would require a specific model for the description of the change in GaAs crystallinity.

A STEM of cross-sectionally thinned specimens also reveals features differing widely between 2D and 3D samples. Figure 2(a) (SLS A with $L_w = 2$ ML) shows continuous InAs layers, with no defect in the structure. On the other hand, Fig. 2(b) (SLS B structure with 3D nucleation) displays the diffraction contrast due to the presence in the well layers of stress centers, whose strain fields extend in the neighboring GaAs layers.

X-ray microanalysis shows that these centers are richer in indium than the well region surrounding them. These In-rich clusters, whose sizes are less than 100 Å tend to align along the growth direction between successive wells, although they are spaced by 280-Å-thick GaAs layers. This memory effect confirms that the whole thickness of the GaAs layer is strained, and moreover nonuniform in the growth plane.

Photoluminescence (PL) was performed on the samples at 77 K.[6] Figure 3(a) shows a spectrum for a SLS B structure grown under the 2D conditions. The quantum well consists of two individual InAs monolayers ($L_w = 1$ ML) separated by 10 Å of GaAs. It must be pointed out that the linewidth is very narrow ($\Delta E = 10$ meV) in view of the total "well" thickness ($L_t = 16$ Å). In the case of 3D nucleation [Fig. 3(b)] the PL is shifted by 280 meV towards lower energy for $L_w = 2.5$ ML. The shift is characteristic of the cluster formation and is always observed with samples having 3D nucleation. Furthermore, the peak is broad ($\Delta E = 50$–100 meV). This can be attributed to the distribution of the size of clusters. This shift in luminescence line varies with l_w.

In conclusion, binary InAs/GaAs SLS's have been grown on GaAs substrates. The sharp transition from the 2D nucleation to the 3D was observed by x-ray diffraction, STEM, and photoluminescence. It has been shown that even when In-rich clusters are formed, good crystalline quality material can be obtained. Also, specific and intense photoluminescence is associated with the cluster formation. These kinds of structures are thus proved to be of interest to study low-dimensional (<2) objects showing good optical properties.

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