

**A BURIED HETERO-STRUCTURE InP-BASED
OPTO-ELECTRONIC DEVICE WITH NATIVE
OXIDIZED CURRENT BLOCKING LAYER**

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FIELD OF INVENTION

The present invention pertains to the field of buried hetero-structure InP based opto-electronic devices, and more specifically to an improved method of manufacturing such devices.

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BACKGROUND OF THE INVENTION

It is well-known that InP-based opto-electronic devices, such as distributed feedback (DFB) laser, distributed bragg reflector (DBR) laser, Fabry-Perot laser, waveguide, optical switch, amplifier, modulator and integrated devices etc., play an important role for optical fiber communication systems. Buried hetero-structure (BH) laser with reverse P-N junction for lateral carrier confinement is one of the best type of InP based opto-electronic devices because of its high performances such as high power output, low threshold current, stable transverse mode and high speed modulation capability.

However, the conventional fabrication process of such BH InP-based opto-electronic devices is very complicated. Although this problem is relevant to many devices, we will focus on the DFB laser because BH DFB laser is the most important device and is also the most difficult device to

fabricate. Other BH InP-based devices can be similarly fabricated without the grating. Fig.1 illustrates a typical buried hetero-structure DFB laser processing procedure, which comprises the following steps: (1) first growth of buffer layer, cladding layers and active layer; (2) fabrication of grating and
 5 (3) regrowth of cladding layer; (4) deposition of dielectric film such as SiO₂ or Si₃N₄ film and wet etching of above layers into specific strip rib; (5) selective regrowth of p-n current block layer; (6) removal of dielectric film and regrowth of the cladding and contact layer; (7) wet etching to form two grooves parallel to the first rib to reduce the device capacitance; (8)
 10 deposition of dielectric layers and etching out a window for the contact layer and finally, evaporation of contact metals for both n and p metallisation.

The complexity of the regrowth, selective regrowth, cleaning, deposition and removal of dielectric film, and wet etching of the stripe mesa, greatly increase the cost of BH DFB lasers and reduce the yield.

15 Native oxidation technique is now a very popular method used for optical and carrier confinement in both edge emitting laser and vertical cavity lasers. The principle of native oxidation is to expose heated Al-bearing materials in water vapor saturated gaseous ambient to form an anhydrous oxide of Aluminum, which is very stable and does not degrade
 20 under normal operating conditions. This type of oxide layer is of the same or less than the thickness of the as-grown Al-bearing materials and does not cause disruption or induce strain, and at the same time, the refractive index is less than 2, therefore the oxidized layer will act as electron block and

optical confinement. So this technology greatly facilitates the fabrication process of III-V materials and devices.

This technology is widely used for GaAs based optoelectronic devices containing Al-bearing materials such as AlAs, AlGaAs, AlInP etc.. So in the prior patents and publications, it is only used for GaAs-based materials and devices. See U.S. patent No.5262360 by N.Holonyak, Jr and J. Dadallesasse (AlGaAs native oxide), No. 5550081 by N. Holonyak, Jr., S. A. Maranowski., method of semiconductor device by oxidizing Aluminum-bearing III-V semiconductor in water vapor environment), S. A. Maranowski, A. R. Sugg, E. I. Chen, and N.Holonyak, Jr., Appl. Phys.Lett. 63, 1660 (1993), Y. Cheng, P. D. Dapkus, M. H. MacDougal, and G. M. Yang, IEEE Photonics Technol. Lett. 8, 176 (1996), J. J. Wierer, S. A. Maranowski, N. Holonyak, Jr., P. W. Evans, and E. I. Chen, Appl. Phys. Lett. 8, 176 (1996), D. L. Huffaker, D. G. Deppe, Kumar, and T. J. Rogers, Appl. Phys. Lett. 65. 97 (1994), K. L. Lear, K. D. Choquette, R. P. Schneider, Jr., S. Kiloyne, and K. M. Geib, Electron. Lett. 31, 208 (1995), B. J. Thibeault, E. R. Hegblom, P. D. Floyd, R.. L. Naone, Y. Akulova, and L. A. Coldren, IEEE Photonics Technol. Lett.8, 593 (1996) , P. D. Floyd, B. J. Thibeault, E. R. Hegblom, J. Ko, L. A. Coldren, and J.L.Merz, IEEE Photonics Technol. Lett. 8, 590 (1996).

However, there are no experimental results reported on incorporating native oxidation on InP-based materials and devices. InP-based materials and devices are well known critical components for fiber optics communications, and the processing techniques for making lasers are often

very complicated, just as described above. Therefore, the process to apply the native oxidation technique to InP-based devices, such as BH DFB laser is of great practical importance.

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OBJECT OF THE INVENTION

It is the object of the present invention to provide a cost-effective method of producing InP-based devices which effectively simplifies the processing of the above- mentioned devices.

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SUMMARY OF THE INVENTION

In this invention, the applicants propose to grow Al-bearing material as cladding layer on InP based laser structure instead of the growth of reverse p-n junction as current blocking layers, and to utilize native oxidation technique to form a current blocking layer in the lateral part of the Al-bearing cladding layer, whereas the center non-oxidized region allows current passage. Therefore, this technique can avoid the second regrowth, selective regrowth, deposition and removal of dielectric film and several cleaning procedures proceeding each step. It also obviates the rigid requirement of the special shape of the ridge rib to prevent SiO₂ polycrystal deposition. It only requires two regrowth steps, so the fabrication of BH DFB laser could be greatly facilitated by utilizing native oxidation .

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS.1a through 1h (Prior Art) illustrate the conventional method for
5 fabricating BH DFB lasers .

FIG.2a through 2f illustrate the preferred fabrication method for the oxidized
BH DFB laser.

10 DETAILED DESCRIPTION OF THE INVENTION

In order to better describe the present invention, a brief description of
the processing method for the conventional BH DFB laser is given, as is
illustrated in FIGS. 1a through 1h. The procedure comprises the following.

15 (1) FIG. 1a: an n-doped InP buffer layer 2, lower confining layer 3, active
layer 4 and upper confining layer 5 are grown on InP substrate 1. (2) FIG. 1b:
Fabrication of the grating on the surface of layer 5. (3) FIG. 1c: Regrowth a p-
InP cladding layer 6 on the grating layer 5. (4) FIG. 1d: Deposition of
dielectric layer 7 on the regrowth layer 6 and the wet etching of layers 7, 6, 5,
20 4, 3, and part of layer 2 into a $2\ \mu\text{m}$ wide ridge rib with the ridge direction
normal to the grooves of the grating; the shape of the rib is strictly controlled
to avoid polycrystal deposition on the dielectric film cap layer 7 during the
next selective regrowth. (5) FIG. 1e: p-InP layer 8 and n-InP layer 9 are

selectively grown on both sides of the rib without depositing on the dielectric film 7, so that they will automatically form a lateral current blocking layer beside the active layer. (6) FIG. 1f: Regrowth of p-InP cladding layer 10 and p⁺ InGaAs contact layer 11 on the cladding layer 6 after removal of the film 7.

5 FIG. 1g: To increase the modulation bandwidth, it is required to reduce the capacitance of the device by etching two parallel grooves 12 along either side of the first stripe ridge. (7) FIG. 1h: Deposition of the dielectric film 13 and with a etched window for the p-metal contact 14 to contact layer 13; contact metal 14 is just deposited on one side of the groove with specific
10 shape for high speed modulation. The thinned down substrate is deposited with n-type contact metal 15.

The present invention is illustrated in FIGS. 2a through 2f. The process comprises the following steps. (1) FIG. 2a: An n-typed InP buffer layer 17, lower confining layer 18, active layer 19 and upper confining layer
15 20 are grown on the substrate 16. (2) FIG. 2b: Fabrication of the grating on the surface of layer 20. (3) FIG. 2c: Wet etching layer 17, 18, 19, 20 into 2 μ m wide ridge rib with the ridge direction normal to the grating grooves. (4) FIG. 2d: Regrowth p-InP cladding layer 21, p-type Al-bearing material 22, p-InP cladding layer 23 and p⁺ InGaAs contact layer 24 on the above said
20 ridge. (5) FIG. 2e: Wet etching of two parallel grooves 25 along either side of the ridge rib and utilizing the native oxidation technique to form current blocking layer along the lateral side of the Al-bearing layer 22 while the central part remains non-oxidized for current passage. (6) FIG. 2f: Deposition

of the dielectric film 26 optionally followed by rapid thermal annealing; with an etched window for the P-metal contact 27 to contact layer 24, contact metal 27 is just deposited on one side of the groove with specific shape for high speed modulation; the thinned down substrate is deposited with n-type
 5 contact metal 28.

In the above-mentioned two structures of FIG. 1a - 1h and FIG. 2a - 2f, the layers before fabrication of the grating 5a (FIG. 1b) and 20a (FIG. 2b) are the same. The InP substrate 1 (FIG. 1a) and 16 (FIG. 2a) is n-doped ($\sim 10^{18} \text{ cm}^{-3}$), n-InP buffer layer 2 (FIG. 1a) or 17 (FIG. 2a) ($\sim 8 \times 10^{18} \text{ cm}^{-3}$) is about 1
 10 μm thick; the undoped lower confinement separate layer 3 (FIG. 1a) and 18 (FIG. 2a) and the undoped upper confinement layer 5 (FIG. 1a) and 20 (FIG. 2a) are about 800 ~ 1500 angstroms thick, their energy band gap should be large enough to form a potential barrier for charged carriers; the active layer 4 (FIG. 1a) or 19 (FIG. 2a) could be a bulk structure, a quantum well structure
 15 or a strained quantum well structure. The confinement layer and active layer could be InGaAsP or AlGaInAs quaternary material system, which satisfy the requirement of laser behavior, such as electrical and optical confinement.

For the conventional structure in FIGS. 1a to 1h, p-InP cladding layer 6 ($\sim 5 \times 10^{17} \text{ cm}^{-3}$) is about 1 μm thick; the current blocking InP layer 8 (p-type doped with $\sim 2 \times 10^{18} \text{ cm}^{-3}$) and layer 9 (n-doped $\sim 2 \times 10^{18} \text{ cm}^{-3}$) are
 20 both about 0.5~1.5 μm thick; the p-InP cladding layer 10 ($\sim 5 \times 10^{17} \text{ cm}^{-3}$) is about 1.5~2.0 μm thick; The p⁺ InGaAs contact layer ($10^{18} \sim 10^{19} \text{ cm}^{-3}$) is less than 1.0 μm .

For the present invention of FIGS. 2a to 2f, however, the p-InP cladding layer 21 ($\sim 5 \times 10^{17} \text{ cm}^{-3}$) is about $0.4 \mu\text{m}$ or less thick; the p-doped Al-bearing material 22 ($\sim 5 \times 10^{17} \text{ cm}^{-3}$) preferably be $\text{Al}_x\text{Ga}_y\text{In}_{1-x-y}\text{As}$ bulk or $\text{Al}_x\text{Ga}_y\text{In}_{1-x-y}\text{As}/\text{Al}_u\text{Ga}_v\text{In}_{1-u-v}\text{As}$ superlattice layers, which could be oxidized without resulting in defect and device degradation, normally x and u are > 0.4 and $0 < y$ and $v < 1$ with total thickness in a range from 20 nm to $2.0 \mu\text{m}$, the superlattice layers are strained balanced with one layer containing high x and u value. The p-InP cladding layer 23 ($\sim 2 \times 10^{18} \text{ cm}^{-3}$) is $2 \mu\text{m}$ or less thick; and the p^+ InGaAs contact layer ($10^{18} \sim 10^{19} \text{ cm}^{-3}$) is about $< 1.0 \mu\text{m}$.

The above-mentioned epitaxial layers are grown using low pressure MOVPE technique. The dielectric films 7, 13 and 26 are deposited by a plasma CVD method or e-beam evaporation, they could be SiO_2 , Al_2O_3 , or Si_3N_4 films. The contact metals 14 or 27 are p-ohmic contact which could be Au-Pt-Ti, while contact metals 15 and 28 are n-ohmic contact which could be Au-Ge-Ni, which can be thermally evaporated or sputter-deposited onto the contact epitaxial layer. The contact metal 14 and 27 could be patterned by using conventional photoresist lift-off technique.

The grating formed on the layer 5 (FIG. 1a) or 20 (FIG. 2a) is fabricated by holographic-on-electron-beam photoresist and reactive ion etching technique. The ridge rib and grooves are formed by wet etching, the etching solution could be $\text{Br}:\text{HBr}:\text{H}_2\text{O}$ (1:8:25). The dielectric film, such a SiO_2 is etched either by RIE or wet etching.

The oxidation is carried out by heating the wafer in a water vapor containing environment up to a temperature of about 350 to 500 degree C. Such a moist environment may be generated by flowing a gas, such as nitrogen through water heated to about 80-90 degree C. The flow of the
5 water vapor is continued for about half an hour to 10 hours.

Thus, it will be understood that the present invention makes it possible to facilitate the fabrication of conventional buried hetero-structure distributed feedback laser.

Without the fabrication of grating, we can similarly fabricate other
10 InP-based opto-electronic devices, such as BH Fabry Perot laser, optical amplifier, switch, modulator and integrated by this native oxidization BH technology.

The present invention may be embodied in other specific forms without departing from the spirit or essential characteristics thereof. The
15 presently disclosed embodiments are, therefore, to be considered in all respects as illustrative and not restrictive, the scope of the invention being indicated by the appended claims and all changes which come within the meaning and range of equivalency of the claims are, therefore, to be embraced therein.

CLAIMS

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We claim:

- 1 1. A native oxidized buried heterostructure InP-based opto-electronic
2 device comprising a semiconductor InP substrate, a buffer layer, a ridge
3 mesa containing the lower confinement layer, active layer and upper
4 confinement layer, a first InP cladding layer and a native oxidized Al-bearing
5 layer as current blocking layers at both lateral edges, a second InP cladding
6 layer, contact layer, and the second ridge mesa covered with an insulating
7 layer.
- 1 2. Native oxidized buried-type InP-based devices according to the claim
2 1, wherein the confinement and active layer are InGaAsP or AlGaInAs
3 quaternary material.
- 1 3. Native oxidized buried-type InP-based devices according to the
2 claim, wherein the Al-bearing materials are made of AlInGaAs related
3 material.
- 1 4. Among the native oxidized buried-type InP-based devices according
2 to the claim 1, for BH-DFB laser, wherein the first ridge is directly formed by
3 wet etching after fabrication of the grating on the upper confinement layer.
- 1 5. Native oxidized buried-type InP-based devices according to the claim
2 1, wherein the thickness of the first cladding InP layer is less than 0.4 μm .



1 6. Native oxidized buried-type InP-based devices according to the claim
2 2, wherein the thickness of the Al-bearing layer can vary from 20nm to 2
3 μm .

1 7. Native oxidized buried-type InP-based devices according to the claim
2 1, wherein the thickness of the second InP cladding layer can vary from 0 nm
3 to 2 μm .

1 8. These native oxidized buried-type InP-based devices according to
2 the claim 1 can be applied to DFB laser, DBR laser, FP laser, optical
3 amplifier, waveguide, switch, and integrated devices.



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