Monolithic integration of GaAs and $In_{0.2}Ga_{0.8}As$ lasers by molecular beam epitaxy on GaAs

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Selective area molecular beam epitaxial regrowth of $In_{0.2}Ga_{0.8}As$ lasers through dielectric masks between GaAs laser stripes on a GaAs substrate has been used for the first time to monolithically integrate these two lasers emitting near 1.0 and 0.85 μm, respectively. During regrowth, GaAs laser stripes were protected under a dielectric mask over which polycrystalline material grew, which was later chemically etched away during the fabrication process. The lasers are of the ridge waveguide type and have threshold currents in the 30–35 mA range for cleaved, uncoated facets at room temperature and a T_0 value of 100 K. The overall performance characteristics of these lasers selectively regrown on dielectric coated wafers were comparable to lasers grown over a bare substrate.

Selective area molecular beam epitaxial (MBE) regrowth over patterned wafers with dielectric masks is potentially very useful for monolithic integration of optoelectronic integrated circuits (OEICs). Regrowth masking with dielectrics is commonly used with metalorganic chemical vapor deposition (MOCVD) and liquid phase epitaxy (LPE) where growth is inhibited on the dielectric mask and *in situ* etching is feasible to prepare the regrown interface. Buried heterostructure lasers are grown by MOCVD and LPE in this manner, by surrounding the active patterned ridge with regrown cladding material.[1] However, MBE does not have an *in situ* etching capability and polycrystalline growth takes place on the dielectric mask.[2] Single-step MBE without dielectric masks has been used to realize monolithic integration of *p-i-n* photodiodes with modulation-doped field-effect transistors (MODFET).[3] But, vertical integration with single-step epitaxy suffers from the distributed capacitances of the doped layers from the underlying device in close proximity with the doped layers of the upper device. This integration scheme has added difficulty with fine dimension photolithography during fabrication due to large step height differences. Selective area regrowth over patterned wafers with dielectric masks eliminates parasitic capacitances by the lateral nature of the integration, and the planarity allows for fine lithography.

Selective area MBE regrowth over dielectric patterned wafers has been applied to integration of GaAs waveguides with $In_xGa_{1-x}As/GaAs$ modulators/detectors,[4,5] $In_{0.53}Ga_{0.47}As$ *p-i-n* photodiodes with $In_{0.53}Ga_{0.47}As/In_{0.52}Al_{0.48}As$ MODFETs,[5,6] and InGaAlAs waveguide phase shifters with $In_{0.53}Ga_{0.47}As/In_{0.52}Al_{0.48}As$ MODFETs.[7] These previous studies have shown that by judicial choice of the regrown buffer, reasonable results were possible. However, it was shown that the response times of photodiodes are more sensitive to regrowth than the transconductance of MODFETs,[5] which suggests that optical devices are more sensitive to regrowth. In this letter, we report for the first time monolithic integration and performance characteristics of two ridge waveguide GaAs and $In_{0.2}Ga_{0.8}As$ lasers fabricated using selective area MBE regrowth where the thick cladding layer below the active laser region acts as a buffer layer to yield comparable laser performance to as-grown lasers. The two ridge waveguide GaAs and $In_{0.2}Ga_{0.8}As$ lasers emit near 0.85 and 1 μm, respectively. Having two lasers emitting at two different wavelengths on the same chip is potentially very useful for applications such as wavelength division multiplexing (WDM) for transmission systems.[8,9]

The schematic of the integrated laser structure is shown in Fig. 1. Both lasers are weakly index guided ridge waveguide-type devices.[10,11] The fabrication involves the following steps. First, the GaAs laser structure was grown over a 3° off (100) toward ⟨111⟩A n^+-GaAs planar substrate, which comprises: (i) a 1 μm n^+-GaAs buffer layer, (ii) a 1.5 μm n-$Al_{0.5}Ga_{0.5}As$ lower cladding layer, (iii) a 0.15 μm n-$Al_xGa_{1-x}As$ compositionally graded layer (from $x = 0.5$ to 0.25), (iv) a 100 Å GaAs single quantum well (SQW) active region, (v) a 0.15 μm p-$Al_xGa_{1-x}As$ compositionally graded layer (from $x = 0.25$ to 0.5), (vi) a 1.5 μm p-$Al_{0.5}Ga_{0.5}As$ upper cladding layer, and (vii) a 0.2 μm p-GaAs contact layer. The carrier concentrations are 10^{18} cm^{-3} in the cladding layers and 5×10^{19} cm^{-3} in the contact layer. After growth, a 3000 Å SiO_2 film was deposited with plasma-enhanced chemical vapor deposition (PEVCD). Then, 250-μm-wide photoresist stripes, separated by 250 μm, were delineated on the grown wafer using standard photolithography. Holes were then chemically etched through the SiO_2 and down into the n^+-GaAs substrate.

After chemical cleaning, the patterned wafer was reinserted along with a planar n^+-GaAs substrate into the MBE chamber for the growth of the $In_{0.2}Ga_{0.8}As$ laser. The structure utilizes (i) a 2 μm n^+-GaAs buffer layer, (ii) a 1.5 μm n-$Al_{0.35}Ga_{0.65}As$ lower cladding layer, (iii) a 0.2 μm n-$Al_xGa_{1-x}As$ compositionally graded layer (from $x = 0.35$ to 0.05), (iv) two 80 Å $In_{0.2}Ga_{0.8}As$ quantum wells with 100 Å $Al_{0.05}Ga_{0.95}As$ barrier layers for the active region, (v) a 0.2 μm p-$Al_xGa_{1-x}As$ compositionally graded layer (from $x = 0.05$ to 0.35), (vi) a 1.5 μm p-$Al_{0.35}Ga_{0.65}As$ cladding layer, and (vii) a 0.2 μm p^+-GaAs contact layer.

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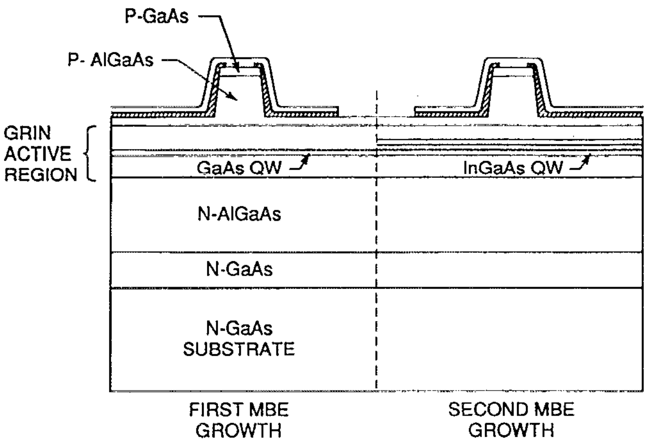

FIG. 1. Schematic of the integrated laser structure.

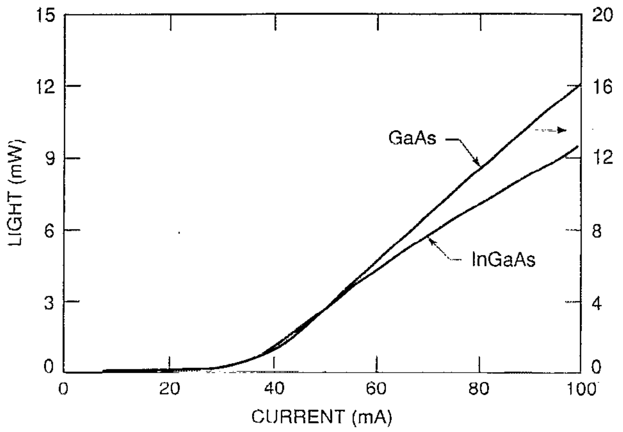

FIG. 2. Light vs current characteristics of the $In_{0.2}Ga_{0.8}As$ and GaAs integrated lasers in a dual wavelength laser chip. The right axis is for the GaAs laser and the left axis is for the $In_{0.2}Ga_{0.8}As$ laser.

After regrowth, the polycrystalline epitaxial material on the SiO_2 regrowth mask is removed by photolithography and chemical etching and the SiO_2 removed to leave a planar wafer with both epilayers displaced laterally by 250 μm. During the fabrication process, 6-μm-wide mesa stripes are etched on the wafer in both epi-regions using a photoresist etching mask and wet chemical etching. The wafer is then processed using standard dielectric deposition and metallization techniques to produce ~250-μm-long laser chips. Similar devices were fabricated on the planar GaAs substrate, grown along side, to produce as-grown $In_{0.2}Ga_{0.8}As$ ridge waveguide lasers for comparison purposes.

Some issues which need to be addressed for selective area regrowth through a dielectric mask are (i) interaction of the dielectric mask with the wafer at elevated temperatures (600–700 °C) for extended periods of time (2–4 h), (ii) interdiffusion of the first epilayer quantum well (QW) during regrowth, (iii) interaction of the growth modes taking place on top the dielectric mask (polycrystalline) with the growth over the patterned wafer (i.e., source of defect formation), (iv) quality of the regrown interface, and (v) quality of the bulk regrown device.

The first issue of the dielectric mask should not play a role in the regrowth. Commonly, PECVD SiO_2 is used as the dielectric material on III-V semiconductors. PECVD of SiO_2 typically takes place using SiH_3 and N_2O at ~300 °C. If the quality of the SiO_2 is very poor, then unreacted species of SiH_3 and N_2O trapped in the dielectric can react with the wafer when raised to ~650° during the regrowth process. However, if the SiO_2 is grown using a slow growth rate to improve quality, then reactivity of the dielectric should not be an issue. The second issue of interdiffusion of the first epilayer QW during MBE regrowth was not quantified for these samples, but some slight energy shift in the emission peak is possible. The third issue of interaction of the polycrystalline growth mode atop the SiO_2 with the growth mode in the trench is minimal. This is because when the trench is lithographically defined, the SiO_2 mask is etched first, then the trench is wet chemically etched with an etchant which undercuts the SiO_2 mask. Thus, the undercut prevents the regrown epilayer from being continuous across the patterned wafer.

The fourth issue of the regrown interface has been characterized extensively by Biswas *et al.*,[12,13] and references therein. Their studies concluded that the regrown interface is characterized by a highly resistive depletion–accumulation region, which is not directly related to impurities or traps but due to a disordered region. Counterdoping of the regrown interface has been employed to overcome this resistivity.[14] The fifth issue of the regrown device quality concerns the remainder of this letter.

The light versus current characteristics of both lasers at room temperature are shown in Fig. 2. The lasers have typical threshold currents in the 30–35 mA range for cleaved, uncoated facets. The as-grown $In_{0.2}Ga_{0.8}As$ lasers also have threshold currents in the 30–35 mA range and quantum efficiencies comparable to the lasers grown on the patterned wafer, which indicates that the epitaxial growth quality is not significantly altered by regrowth. This is perhaps due to the thick bottom cladding layer which acts as a buffer layer, and separates the active region of the device spatially from the disordered regrown interface.

The light versus current characteristics of the lasers at varying temperatures between 20 and 70 °C were measured. The measured threshold current as a function of temperature is shown in Fig. 3 for the two lasers in the dual wavelength chip and also for the as-grown $In_{0.2}Ga_{0.8}As$ laser. The threshold current as a function of temperature for all of these devices can be represented by the usual expression $I_{th}(T) \sim I_0 \exp(T/T_0)$ where $T_0 \sim 100$ K for the temperature range 20–70 °C. The differential quantum efficiency is found to be nearly independent of temperature in the temperature range 20 to 70 °C.

In summary, dual wavelength ridge waveguide laser chips emitting near 0.85 and 1 μm using GaAs and $In_{0.2}Ga_{0.8}As$ active regions have been realized using selective area MBE regrowth over dielectric patterned wafers. Both lasers are of the ridge waveguide type. The lasers have threshold current in the 30 to 35 mA range at room temperature and their temperature dependence of threshold is characterized by a T_0 value of 100 K in the temper-

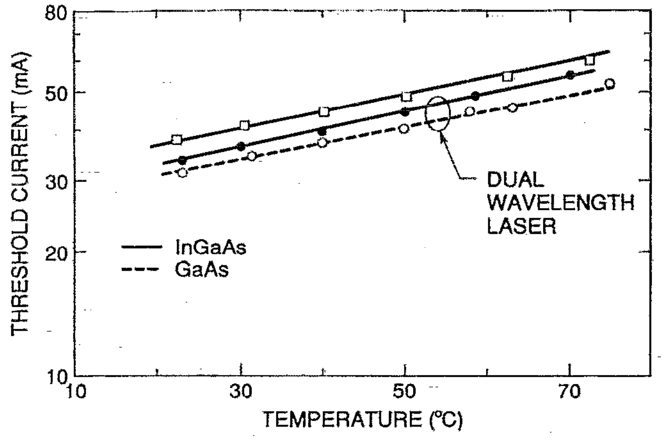

FIG. 3. Temperature dependence of the threshold current densities is plotted for the GaAs and $In_{0.2}Ga_{0.8}As$ lasers in the dual wavelength chip and for the as-grown $In_{0.2}Ga_{0.8}As$ laser (squares).

ature range 20–70 °C. The performance characteristics of the lasers grown over dielectric coated patterned wafers are comparable to that for wafers grown over bare GaAs substrates.

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