Double Heterostructure GaAs/AlGaAs Thin Film Diode Lasers on Glass Substrates

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Abstract—**The epitaxial liftoff approach has been attracting increasing interest as an alternative to lattice-mismatched heteroepitaxy. We report a *thin film* GaAs double heterostructure injection diode laser fabricated on a glass substrate by the epitaxial liftoff technique. This presages the integration of the two major optical communications materials, *III-V* semiconductor crystals with SiO$_2$ glass.**

In THE field of electronic materials, there has been a persistent interest in the integration of high-quality epitaxial thin film semiconductor layers with arbitrary crystalline or glass substrates. For example, thin film GaAs layers on crystalline silicon substrates would allow the combination of the two technologies. This has led to a massive effort on lattice-mismatched heteroepitaxial growth. Recently, however, a new and more flexible approach [1] has been attracting increasing [2] attention.

In this new approach, perfect epitaxial quality AlGaAs thin films are lifted off lattice-matched GaAs growth substrates by means of an ultra-thin AlAs release layer. Advantage is taken of the extremely selective etching ($\geq 10^7$) of AlAs in dilute hydrofluoric acid, permitting large area (cm^2) epitaxial AlGaAs films to become undercut. The GaAs substrate is left intact and can be reused if so desired, while the epitaxial thin film can be cemented or "Van der Waals bonded" by surface tension to any arbitrary substrate. In this letter, we report a *thin film* GaAs injection laser fabricated on a glass substrate by the epitaxial liftoff technique. This presages the integration of the two major optical communications materials, *III-V* semiconductor crystals with SiO$_2$ glass.

For this initial demonstration experiment, a conventional broad area double heterostructure laser design was implemented. As shown in Fig. 1, two additional epilayers had to be incorporated which would not have been present in a conventional laser growth sequence. The bottommost layer was 500 Å of n$^+$-AlAs, which is the selectively etched release layer. This layer, which underlies the entire structure, is selectively removed by dilute hydrofluoric acid, allowing the rest of the epitaxial structure to float freely away from the GaAs substrate. (Aluminum compositions below 40 percent are not etched and remain intact.) Above the release layer is the second special epilayer, 1.5 μm of n$^+$-GaAs to provide sheet conductivity below the laser because the glass substrate is an insulator. The rest of the organometallic chemical vapor epitaxy (OMCVD) growth sequence is conventional: 1.5 μm of n-Al$_{0.3}$Ga$_{0.7}$As lower cladding layer, 0.2 μm GaAs active layer, 1.5 μm of p-Al$_{0.3}$Ga$_{0.7}$As upper cladding layer, and a 0.2 μm p$^+$-GaAs ohmic contact layer.

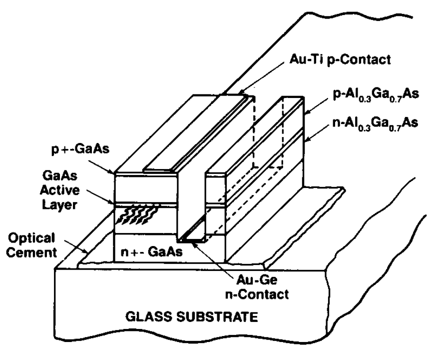

Fig. 1. A perspective view of a thin film GaAs double heterostructure laser on a glass substrate. The entire structure is $\sim 4.9\ \mu$m thick with the vertical scale greatly exaggerated in this perspective since the active laser stripe is 100 μm wide. Since the glass is an insulator, the laser required an n$^+$-GaAs layer below, which was contacted through the opening above.

All the processing steps were completed prior to the thin film liftoff procedure. Separate and sequential resist-spin-on, exposure, and metallization steps were followed for both the p-metal (Au/Ti) and n-metal (AuGe) contacts. We emphasize again, that due to the insulating substrate, both electrical contacts had to be made to the top surface. The p-metal stripe was 100 μm wide and the n-metal stripe was 70 μm wide, with a 25 μm space between the two stripes. After developing the second resist, but prior to the n-metal evaporation, a 3.5 μm deep moat was etched down to expose the underlying n$^+$-GaAs layer. This moat etching required 30 min in H$_2$SO$_4$:-H$_2$O$_2$:H$_2$O (1:8:500). The p and n contacts were then simultaneously alloyed at 420°C for 20 s in an Argon purged rapid thermal annealer.

Following the metallization processing steps, the top surface was coated with Apiezon W wax in the manner described in [1]. The individual chips of dimension $\approx 0.55 \times 5$ mm were diamond cleaved from the original growth substrate, with the 0.55 mm axis defining the cavity length and the 5 mm axis allowing space for 20 separate lasers. After 1 h at 0°C in 10 percent dilute HF acid solution, the epilayers floated off the GaAs substrate, supported by the wax. These thin epilayers films could be handled provided they were supported by the wax coating. They could be mounted on both glass and silicon substrates either by ultraviolet curable optical fiber splicing

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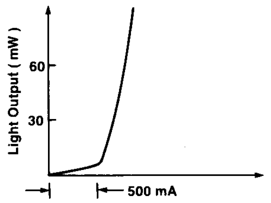

Fig. 2. A light output versus current curve. On the identical devices, the threshold current was unchanged before and after liftoff.

cement (Norland 61 spun on at 5000 rpm) or by direct "Van der Waals bonding" by surface tension. Then the wax was dissolved away in trichloroethylene leaving the devices ready for testing.

A standard laser test station was employed to investigate the laser performance under low-duty cycle operation at 1 kHz repetition rate and 400 ns electrical pulse duration. A typical light output versus current input curve is shown in Fig. 2. The same devices could be monitored both on their original growth substrate and later after liftoff on their new substrates. We found that the same devices had the same laser threshold current density (≈ 1000 A/cm^2) both before and after liftoff. Differential quantum efficiency was ~ 20 percent from a single facet. This laser performance is typical of what could be expected of this conventional design whether the laser had been grown with the AlAs release layer or without. (In fact, [1] shows that 600 ns minority carrier lifetimes can be grown over an AlAs layer and that lifetime maintained after liftoff.)

In the future, there is no doubt that more sophisticated, graded index, separate confinement quantum well heterostructure designs can also be implemented in this way with a corresponding improvement of performance characteristics.

Although glass is a poor thermal conductor, there are benefits in direct Van der Waals bonding by surface tension to a good thermal conductor like diamond. We were somewhat hindered in implementing this Van der Waals bond in the particular epilayer structure shown in Fig. 1. Due to the slight lattice mismatch between the $Al_{0.3}Ga_{0.7}As$ waveguiding layers and the GaAs layers, an overall concave curvature developed after liftoff, whereas a convex curvature is preferred as explained in [1]. This is now being rectified by balancing the thicknesses of the n^+ and p^+ layers on either side of the active layer.

Unlike lattice mismatched heteroepitaxy, there is no compromise in the epitaxial quality [1] of the liftoff films. We anticipate that the epitaxial liftoff approach will find use wherever there is a desire to combine thin film *III–V* semiconductor crystals with other materials and substrates.

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