Stripe-geometry GaAs-InGaAs laser diode with back-side contact on silicon by epitaxial lift-off

J.C. Fan, K.Y. Chen, Gray Lin and C.P. Lee

The transfer of a preprocessed stripe-geometry GaAs-InGaAs laser diode film onto a Pd/Ge/Pd coated n'-Si substrate is reported with the backside contact on Si using epitaxial lift-off (ELO) technology. The Pd/Ge/Pd metal layers provide ohmic contacts to both the Si substrate and the GaAs film, making vertical conduction through the Si substrate possible. No device degradation was observed after the ELO process and comparable results were obtained for the ELO laser diodes and the diodes without the ELO process.

The integration of semiconductor lasers with silicon electronic circuits has always been a subject of great interest. This type of III-V/Si integration is important for applications such as optical communications and optical interconnections [1, 2]. Many approaches including heteroepitaxial growth and material bonding techniques have been developed for this purpose [3-9]. However, heteroepitaxial growth of GaAs laser diodes on Si suffers from a high dislocation density due to a large lattice mismatch. The poor material quality causes the lasers to degrade [10]. Conversely, wafer bonding techniques such as bonding by atomic rearrangement [6] and epitaxial lift-off (ELO) [8, 9] have the advantage of combining two different materials with different crystal structures.

Yablonovitch et al. [9] and Pollentier et al. [8] have demonstrated ELO GaAs-AlGaAs broad-area lasers on a glass and an Si substrate. However, bonding a laser diode film on glass or a bare Si substrate by the Van der Waals force creates an insulating interface, which prohibits vertical conduction between the laser and the Si substrate. Hence, both the n- and p-type contacts must be fabricated on the front side of the grifted film. In this Letter, we describe an ELO technique for the fabrication of stripe-geometry laser diodes on an Si substrate with the backside contact on Si. Vertical conduction through the Si substrate was obtained and no device degradation was observed after the ELO process.

We have recently found that very good ohmic behaviour can be obtained between a GaAs thin film and an Si substrate if the ELO-GaAs film is grafted onto a Pd/Ge/Pd coated Si [11]. This technique is applied here to fabricate an ELO laser diode on Si. The strong metallurgical bonding between the GaAs thin film and the Si substrate also makes the facet cleavage possible without any danger of breaking the grafted film and the substrate.

The lasers used in this study were 980nm InGaAs/GaAs strained single quantum well lasers grown by MBE. The whole structure is the same as a conventional GRINSCH laser, except an n-AlAs sacrificial layer (100Å thick, Si = 5 x 10^10 cm^-2) was grown between the laser structure and the substrate. Conventional ridge waveguide lasers with a 5μm width were fabricated. The preprocessed laser diodes on the GaAs substrate were covered with black wax on top and soaked in 10% HF solution to selectively remove the AlAs layer. The ELO film, after separation from the GaAs substrate, was dipped in HCl and HF before the bonding process.

The n'-Si substrate (R = 0.01-1Ω·cm) was used as the host substrate in the ELO process. A 1000Å Pd/1300Å Ge/2500Å Pd metallic multilayer was deposited on the Si substrate by an electron-gun deposition system under a base pressure of ~8 x 10^-5 torr. After deposition, the Si substrate was lapped down to 100μm thick, and a 5000Å thick Al film was evaporated onto the backside as the back side ohmic contact. The prepared 100μm thick n'-Si substrate with Pd/Ge/Pd metallic overlayer was then dipped in an HF solution. Finally, the ELO laser film and the n'-Si substrate were bonded together by Van der Waals bonding. The bonded sample was heated in a furnace at 400°C for 30min under a forming gas ambient. No external pressure was needed during the heat treatment. Ohmic contacts were formed at this stage both at the interface between the grifted film and the Si substrate and the backside of the substrate. As described in our previous work, the ohmic contact formed by Pd/Ge/Pd provides a low resistance conduction path between the film and the substrate [11]. The bonded sample was then cleaved into bars along the [110] direction. This metallurgical bonding at the interface provides enough strength for the facet cleavage process. A schematic diagram of the finished device is shown in Fig. 1.
clearly see the uniform and smooth bonding interface between the cleaved facet of a laser diode. From the photograph, we can characterize of a bonded laser/silicon diode with a cavity. The threshold current was 16.3mA and the slope efficiency was 0.4W/A per facet without facet coating. For comparison, we also include a light-current curve for a laser diode on GaAs substrate without the ELO process. The results are very similar between the two. To our knowledge, this is the first successful fabrication of an ELO stripe-geometry laser diode on Si without performance degradation.

In summary, we have demonstrated an ELO stripe-geometry laser diode on an Si substrate with the backside contact on Si. The performance is similar to that of a conventional laser diode on a GaAs substrate.

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References
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