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Wafer Bonding of InP to Si and Its Application to Optical Devices

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I. Introduction

Integration of III-V optical devices on Si is an essential technology to realize optoelectronic integrated circuits (OEICs). Especially, fabrication of InGaAsP/InP long-wavelength lasers on Si is very attractive for optical interconnections between Si LSI chips because Si is transparent at the lasing wavelength.

We have been investigating wafer bonding as a key technology to integrate InGaAsP/InP lasers on Si and fabricated edge-emitting and surface-emitting lasers. In this report, we review the bonding technology and discuss the laser fabrication and characteristics.

II. InGaAsP edge-emitting lasers on Si

We have fabricated InP edge-emitting lasers on Si using the bonding technology and achieved room-temperature CW operation [1]. The device fabrication process is illustrated in Fig. 1. First, a double heterostructure (DH) is grown on a (100) p-InP substrate using MOVPE, and it includes an InGaAs etch-stop layer, a p-InP cladding layer, an InGaAsP active layer (d=0.15 μm, λgap = 1.3 μm), an n-InP cladding layer, and an n-InGaAs cap layer. The epitaxial wafer is then stuck on a glass plate with wax for mechanical support (Fig.1(a)). Next, the p-InP substrate and InGaAs etch-stop layer are selectively etched to leave a thin DH film on the glass plate and the surface of the exposed p-InP cladding layer is cleaned with an H_2SO_4:H_2O_2:H_2O (3:1:1) solution. Surface of a Si substrate is also treated with the same solution, and the cleaned surfaces are placed in contact at room temperature (Fig. 1(b)). The wafers adhere to each other at this step through hydrogen bonding between OH-groups absorbed on the wafer surface during the cleaning [2].

After bonding at room temperature, the wafers are immersed in warm solvent to dissolve the wax completely and detach the glass plate from the wafers. The sample is then annealed in an H_2 atmosphere at 400 °C for 30 min to increase the bonding strength (Fig. 1(c)). Finally, as shown in Fig. 1(d), 8-μm-wide mesa stripes and ohmic contacts are formed and cleaved into 270-μm-long cavities.

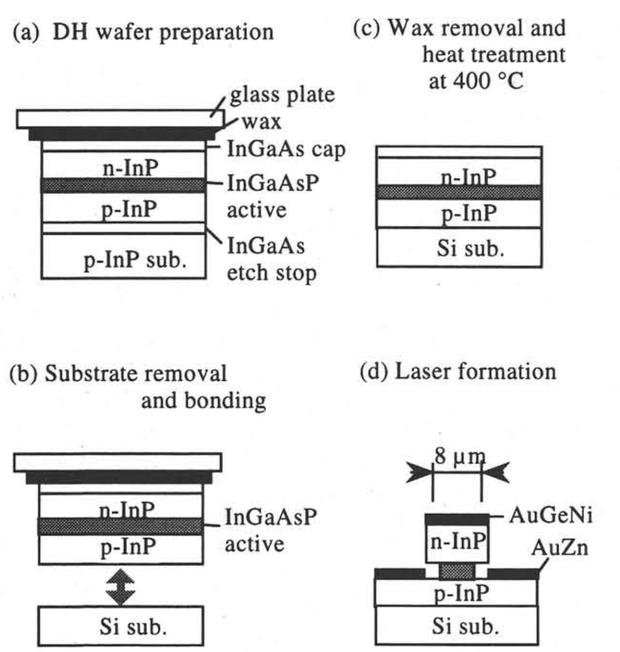

Fig. 1: Fabrication process of InGaAsP edge-emitting lasers on SI by wafer bonding.

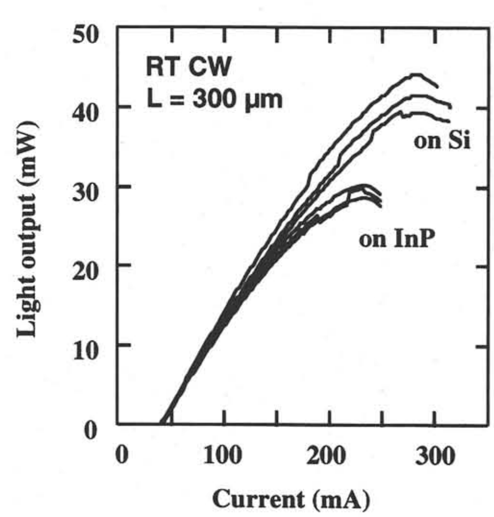

Fig. 2: Light-current characteristics of the edge-emitting lasers under room-temperature CW excitation.

Fig. 2 shows the typical light-current (L-I) characteristics of the devices under room-temperature CW excitation. For comparison, the same laser structures were fabricated on p-

InP substrates and their L-I curves are also shown in this figure. The threshold currents are identical (I_{th} = 39 mA) for both lasers, indicating high quality InP materials can be integrated on Si by wafer bonding. Additionally, higher output powers have been obtained with lasers on Si, which is due to higher thermal conductivity of Si substrates

III. InGaAsP surface-emitting lasers on Si

We have also fabricated InP surface-emitting lasers on Si and achieved room-temperature photopumped operation [3]. Fig. 3 shows the schematic structure. The fabrication process is similar to that for edge-emitting lasers and an InGaAs(P)/ InP MQW active region (emission wavelength : 1.55 μm) with 40.5-pair InP/InGaAsP (λgap = 1.42 μm) mirror is bonded on a 3.5-pair Al_2O_3/a-Si stacked mirror which is previously sputtered on a Si substrate.

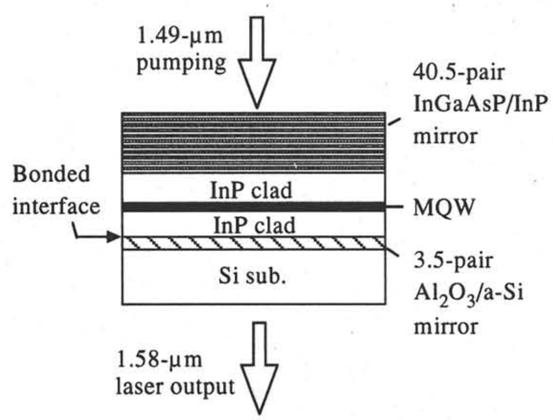

Fig. 3: Schematic structure of InGaAsP surface-emitting lasers on Si fabricated by wafer bonding.

The fabricated structure was optically pumped by a 1.49-μm semiconductor laser through the InGaAsP/InP mirror. The pumping laser was operated under a pulsed condition with 1-μs pulses at 1 kHz. The pumping light was focused on the sample using a hemispherical fiber with a measured spot size of 15 μm in diameter. The cavity resonant light at 1.587-μm was collected through the Si substrate and detected using a Ge photodetector with a lock-in amplifier. Fig. 4 shows light output versus input power (L-L) characteristic at room temperature. A distinct lasing threshold was clearly observed at the input power of 14.4 mW. The FWHM of the emission spectrum wad found to be reduced as the pumping power increased and reached an almost constant value of 1.6 nm above the lasing threshold. Moreover, more than 90 % of the emitted light was confirmed to be linearly polarized along the (110) orientation above the threshold. The threshold current density deduced from the measured threshold optical power is calculated to be around 2 kA/cm^2, which indicates that the effective mirror reflectivity higher than 99% is realized in this cavity.

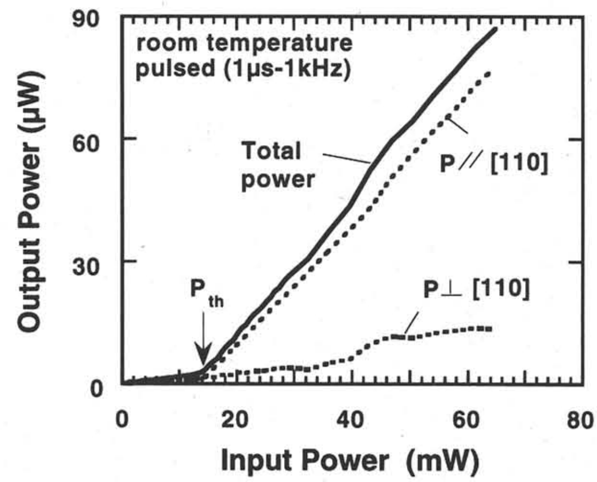

Fig. 4: Light output versus input power characteristics at room temperature.

IV. Conclusions

We have investigated wafer bonding of InP to Si and fabricated InGaAsP/InP long wavelength lasers on Si. Room temperature CW operation of edge-emitting lasers and photopumped operation of surface-emitting lasers have been achieved. This bonding technology is promising to realize high quality optoelectronic-VLSIs.

References

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