Continuous-Wave Lasing from DVS-BCB Heterogeneously Integrated Laser Diodes

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Abstract: Continuous-wave lasing from heterogeneously integrated laser diodes, bonded using DVS-BCB adhesive bonding, is presented. An integrated heat sink structure and reduction of the power dissipation resulted in room-temperature continuous-wave lasing with 1.9mW maximum output power.

OCIS codes: (140.5960) Semiconductor lasers; (250.5300) Photonic integrated circuits

1. Introduction

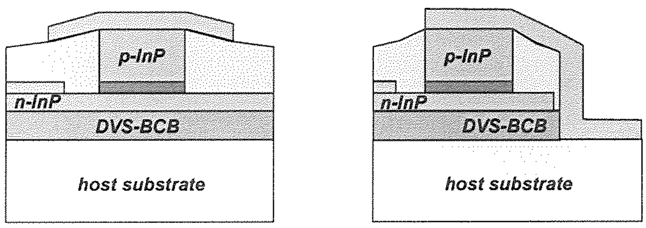
Silicon-on-insulator (SOI) is an emerging material platform for photonic integration, due to the large omni-directional refractive index contrast that can be achieved. Moreover, the massive CMOS processing infrastructure can be used to process these optical components. The integration of light emitters, amplifiers and detectors in the near-infrared is hampered by the indirect band gap of silicon. Although several advances are being made to achieve light emission from silicon, either by changing the silicon material on a nano-scale or by exploiting its non-linear optical properties, in the foreseeable future these devices will not outperform their III-V semiconductor counterparts, supplying state-of-the-art optoelectronic components for the telecommunication market nowadays. In order to create photonic integrated circuits comprising both active and passive optical components, the heterogeneous integration of passive silicon-on-insulator waveguide circuits and active InP/InGaAsP components was proposed in literature. In [1], electrical-injection-based continuous-wave lasing was achieved from a hybrid AlGaInAs-silicon evanescent laser. The AlGaInAs epitaxial layer structure was bonded to the SOI waveguide circuit using molecular wafer bonding. We demonstrated laser action in an InP/InGaAsP layer integrated on and coupled to an SOI waveguide circuit [2]. In this case, a DVS-BCB adhesive layer was used for bonding the III-V epitaxial layer stack to the SOI waveguide wafer. Adhesive bonding is an attractive process, due to the lower particle and surface roughness sensitivity compared to molecular bonding, the low bonding temperature and low cost of the technology. Moreover, a large range of bonding layer thicknesses can be achieved, which makes it a versatile process. On the other hand, molecular bonding avoids the use of organic materials at the bonding interface, which might improve the long-term stability of the bond. As the molecular bonding approach requires particle-free and low-roughness surfaces to obtain void-free bonds, there are yield issues in this approach, as the obtainable quality of III-V epitaxial layer structures is inferior to the obtainable quality of for example silicon wafers. One major drawback of the DVS-BCB adhesive bonding process, especially for the integration of active opto-electronic devices, is the low thermal conductivity of DVS-BCB (0.3W/mK). This low thermal conductivity leads to a high thermal resistivity of the bonded devices, which prevented reaching continuous-wave lasing in [2], due to thermal runaway of the DVS-BCB bonded laser diodes. In this paper, we will present the use of an integrated heat sink structure to reduce the thermal resistivity of the bonded device and the use of an improved fabrication process which lowers the power dissipation in the bonded laser diode.

2. DVS-BCB heterogeneous integration process

The developed DVS-BCB bonding process is discussed in detail in [3], for the case of a III-V die that is bonded to a processed SOI waveguide wafer. In order to remove particles from the surfaces to be bonded, the silicon-on-insulator waveguide wafer is cleaned using a Standard Clean 1 solution (SC-1), which lifts particles from the surface and prevents redeposition. On the III-V die, a sacrificial InP/InGaAs layer pair is removed using wet chemical etching, which lifts particles from the die surface and leaves a wafer surface free of hydrocarbon contamination. After surface activation of the III-V die using HF, in order to maximize the bonding strength, DVS-BCB is spin coated on the host substrate and is pre-cured, in order to evaporate the solvents remaining in the DVS-BCB layer. After pre-cure, the III-V die is bonded, epitaxial layers down, to the host substrate in a vacuum environment, in order to avoid the formation of cavities at the bonding interface. After pressurized curing at 250C for 1 hour, the InP substrate is removed, using a combination of mechanical grinding and wet chemical etching using $3HCl:H_2O$, until an InGaAs etch stop layer is reached. After substrate removal, opto-electronic components can be fabricated in the bonded epitaxial layer structure. In order to prevent the generation of dislocations in the bonded III-V epitaxial layer, which increases the power dissipation in the bonded device due to the deterioration of the epitaxial layer quality, the post-bonding temperature excursions are kept below 300C. In this way, the stress in the III-V epitaxial layer, caused by the thermal expansion coefficient mismatch between silicon and InP/InGaAsP, is kept low enough in order to ensure no dislocation generation.

3. Bonded laser diodes with an integrated heat sink

The cross-section of a standard DVS-BCB bonded laser diode structure is schematically shown in figure 1a. As all heat has to be sunk through the DVS-BCB bonding layer, the thermal resistivity of the bonded device is high. In order to reduce the thermal resistivity of these DVS-BCB bonded laser diodes, in this paper the use of an integrated heat sink structure is proposed. The layout of the integrated heat sink structure is shown in figure 1b. By connecting the plated gold top contact to the host substrate, through the bonding layer, heat sinking is achieved, provided that the plated gold contact is sufficiently thick. Also the side contact can be connected to the underlying substrate (while preventing a short-circuit between both contacts) to reduce the self-heating of the bonded laser diode.

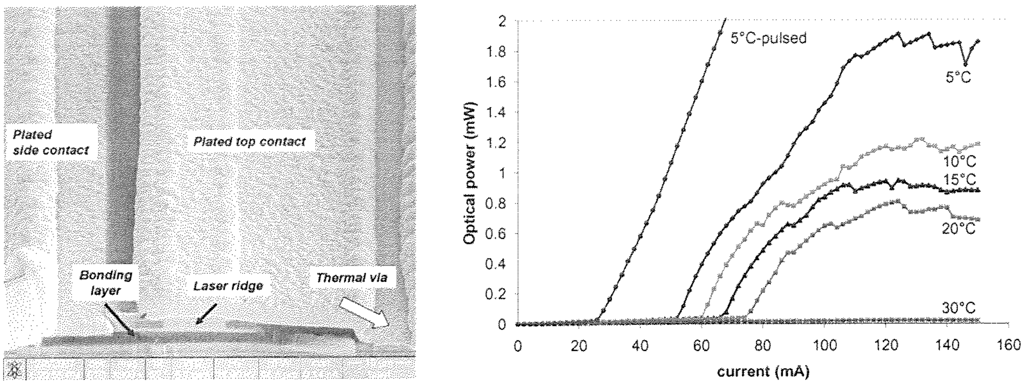


(a) (b)

Fig. 1 Device layout of standard DVS-BCB bonded laser diodes (a) and the proposed laser diode structure with integrated heat sink (b)

4. Measurement results

An SEM image of a fabricated DVS-BCB bonded laser diode with the improved fabrication process and with an integrated heat sink structure is shown in figure 2a. Although thinner bonding layers (300nm) can be achieved, a 2μm thick DVS-BCB layer is used in this case, in order to demonstrate the improved performance of the device by the improved fabrication process and the integrated heat sink. The laser diode contacts consist of 3μm thick plated gold top contact. The laser ridge is 10μm wide and the thermal via is located 20μm away from the laser ridge. After bonding and laser diode fabrication, 700μm long laser bars were cleaved. The optical power versus current characteristics of the bonded laser diodes at various temperatures of the temperature controller on which the laser bar was mounted, are shown in figure 2b. These measurement results present, for the first time, continuous-wave lasing from a DVS-BCB bonded laser diode, through the improved laser diode fabrication process and the integration of a heat sink structure. A maximum output power of 1.9mW is obtained at 5C. The laser threshold is 52mA and the differential quantum efficiency (taking into account both laser facets) is 11.8%. The laser diode has a characteristic temperature of 43K. By comparing the laser versus current characteristic under pulsed operation and continuous-wave operation, a substantial deterioration due to self- heating of the bonded device can still be seen. This prevented lasing at temperatures higher than 30C. The spectral characteristics at different current levels above laser threshold at an ambient temperature of 5C is shown in figure 3.



(a) (b)

Fig. 2 SEM image of a fabricated laser diode structure with the thermal via (a) and measured continuous-wave lasing from DVS-BCB bonded laser diodes (b)

The shift in the emission wavelength, due to the self-heating of the bonded device, is clearly observable. From this shift in the emission wavelength, we can deduce a thermal device resistance of about 500C/W (assuming a thermal band gap shrinkage parameter dE_g/dT=-0.28meV/K). While this thermal resistivity allowed continuous-wave lasing, a further self-heating reduction is required in order to achieve lasing at higher ambient temperatures. This can be achieved by using narrower laser stripes, thinner DVS-BCB bonding layers and lower laser thresholds by applying high-reflectivity coatings to the laser facets.

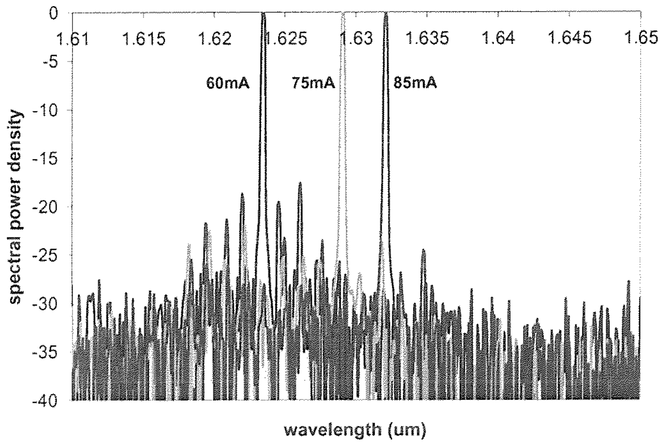


Fig. 3 Spectral characteristics of the bonded laser diode at an ambient temperature of 5C for various currents

5. Conclusions

In this paper, we presented for the first time continuous-wave lasing from a DVS-BCB bonded laser diode by incorporating a heat sink structure in the laser diode design. This demonstration paves the way to using these bonded laser diodes on SOI integrated circuits and to integrating semiconductor optical amplifiers, using an integration process that is flexible, low cost and relatively insensitive to the quality of the wafer surfaces to be bonded, holding the promise of high yield fabrication.

6. References

[1] A.W. Fang, H. Park, O. Cohen, R. Jones, M.J. Paniccia, and J.E. Bowers, "Electrically pumped hybrid AlGaInAs-silicon evanescent laser," Opt. Express **14**, 9203-9210 (2006)

[2] G. Roelkens, D. Van Thourhout and R. Baets, "Laser emission and photodetection in an InP/InGaAsP layer integrated on and coupled to an SOI waveguide circuit", Opt. Express **14**, 8154-8159 (2006)

[3] G. Roelkens,J. Brouckaert, D. Van Thourhout, R. Baets, R. Nötzel and M. Smit, "Adhesive bonding of InP/InGaAsP dies to processed SOI wafers using DVS-bis-BCB", J. Electrochem. Soc. **153**, G1015 (2006)

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