High output power GaAs-based Vertical External Cavity Surface Emitting Lasers achieved by $AuIn_2$ Solid Liquid Inter Diffusion Bonding

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One of the limiting factors to the performance of III-V electronic and opto-electronic components is the low thermal conductivity of the deployed material systems (69 W/mK for InP, 50 W/mK for GaAs). Previously, thermal bonding at high temperatures (>400°C) has been used to transfer the active part of various structures onto different carrier substrates that have a better thermal conductivity. One of the intrinsic problems of this technology is the resulting strain within the final structure due to the different thermal expansions coefficients of active and carrier material.
Here, a low thermal $AuIn_2$ bonding is used to avoid the introduction of additional strain into the structures. Solid liquid inter diffusion (SLID) has been introduced since the required bonding temperature is only ~200°C. At the same time, once the alloy is formed, the bonding interface is capable of withstanding high temperatures (the melting point of the alloy is 480°C) required for further processing steps. This form of bonding has been first described by Bernstein [1].
To investigate the influence of the $AuIn_2$ bonding and the choice of the carrier substrate on the device performance, a 980 nm vertical external cavity surface emitting laser (VECSEL) was grown in reverse order by MOCVD. On top of an AlGaAs etch stop layer 5 InGaAs quantum wells (QWs) were grown, followed by a 28 period GaAs/AlAs Bragg mirror (Fig. 1). In addition, a 'traditional' VECSEL structure was grown on GaAs substrate consisting of the same 28 period GaAs/AlAs mirror and 5 InGaAs quantum wells (Fig 2).
To improve the evacuation of the dissipated heat, the VECSELs were bonded to Si (wafer thickness 280 µm) and SiC (wafer thickness 270 µm) that have a thermal conductivity of 150 W/mK and 300 W/mK respectively as compared to 50 W/mK for GaAs.
The $AuIn_2$ alloy is formed with a weight concentration of 54% of indium. To achieve this weight concentration the following metalisations are applied. A 30 nm thick Ti layer was evaporated to improve the adhesion between the Au layer and the structure for both parts followed by the following metals: 150 nm Au, 600 nm Indium and 20 nm Au on top of the active structure and 150 nm of Au on the carrier substrate.
The gold layer is evaporated on top of the carrier substrate to prevent Indium oxydation. A schematic view of the metalisation can be found in Fig. 2. A pressure of about 10 MPa is applied while the temperature is ramped to 200°C and maintained for 30 minutes. While cooling down, the pressure is kept constant. After bonding the active layer to the carrier substrate, chemical-mechanical polishing has been used to remove the GaAs substrate and the etch-stop layer to expose the resonator.
The sample is mounted on a copper block and the temperature of the device substrate is controlled by a Peltier module. The second mirror fomring the cavity has a reflectivity of 99% and a radius of curvature of 50 mm. The length of cavity is 10 mm. The measurements were carried out at a Peltier temperature of 11°C. The device is optically pumped using a cw 808 nm emitting laser diode. The cw pump beam is focused with a spot size of w_p=50 µm and at a 45° incidence angle on the sample.
Measurements on the 'traditional' GaAs VECSEL structure showed a maximum output power of 100 mW. The maximum output power could be increased by a factor of more than 7 for the VECSEL bonded to the Si substrate. However, a thermal roll over could still be observed. This was not the case for the VECSEL bonded to the SiC substrate. Here, we obtained a preliminary maximum output power of more than 15 times the one of the GaAs VECSEL. The obtained results clearly indicate the benefits of this technology for high power devices. An excellent thermal contact was obtained by SLID $AuIn_2$ bonding and further improvements are to be expected. More detailed measurements will be carried out and discussed.
We would like to point out that the same technology is applicable for InP-based devices [2].

Références

[1]L. Bernstein 'Semiconductor joining by the solid-liquid interdiffusion (SLID) process', *J. Electrochem. Soc.*, 113, pp1282-1288, Dec 1966
[2]C. Symonds, J. Dion, I. Sagnes, M. Dainese, M. Strassner, L. Leroy, J.-L. Oudar, 'High performance 1.55 µm vertical external cavity surface emitting laser with a broadband integrated dielectric-metal mirror', accepted for publication in IEE Elect. Lett., May 2004

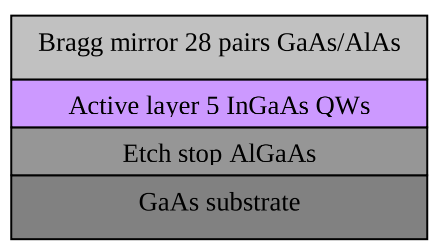

Fig. 1 GaAs-based VECSEL structure for bonding

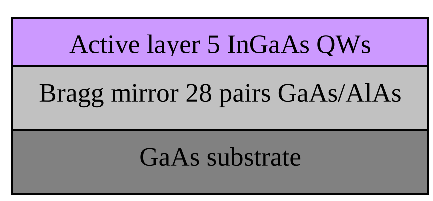

Fig. 2 GaAs-based VECSEL

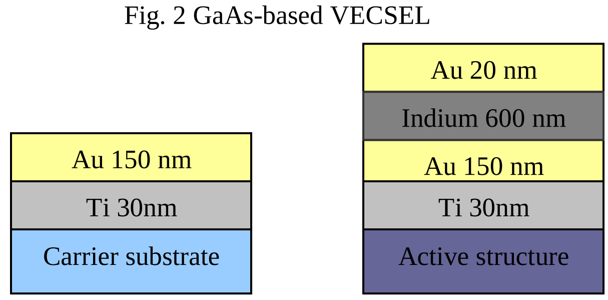

Fig. 2 Metalisations evaporated on the carrier substrate and the active structure.