High Temperature Hybrid Silicon Micro-ring Lasers with Thermal Shunts

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Abstract: We demonstrate a hybrid silicon micro-ring laser design with novel thermal shunts. With this technique the hybrid silicon ring lasers with a 50 μm diameter operate continuous wave up to 105 °C.

OCIS codes: (140.2020) Diode lasers; (140.3560) Lasers, ring; (140.6810) Thermal effects

1. Introduction

A hybrid silicon micro-ring laser is a good candidate as light source for low cost and low power consumption data links [1]. However, thermal issues are one of major obstacles to achieve higher energy efficiency and higher integration density. The thick buried oxide (BOX) layer in silicon on insulator (SOI) has a poor thermal conductivity and blocks the heat dissipating into the heat sink. Furthermore ring lasers have a higher thermal impedance due to their small footprint, which makes the performance degrade rapidly at high temperatures [2]. In previous work we reduced device heating with a metal thermal shunt design [3]. In this paper we investigate better thermal management of hybrid silicon ring lasers with an optimized thermal shunt structure.

2. Ring laser design with thermal shunting

The laser structure with thermal shunts is illustrated in Fig. 1 (a). The III-V ring mesa has 5 InAlGaAs QWs with the center photoluminescence peak at 1310 nm. By etching through the BOX layer to locally sink heat from laser mesa to the silicon substrate through good thermally conductive material, gold in this research, the heat generated in the active region of laser is able to dissipate to the substrate through the shunts. In order to take the advantage of electrodes layout, the thermal shunt was separately laid underneath the p- and n- type metal pads. Insulating layers are needed between shunt metal and ring mesa in order to avoid extra optical loss. An insulating layer with high thermal conductivity is preferred. We chose SiN_x and SiO_2 for process convenience, of which the thermal conductivity was measured to be 1~1.5 W/(m·K).

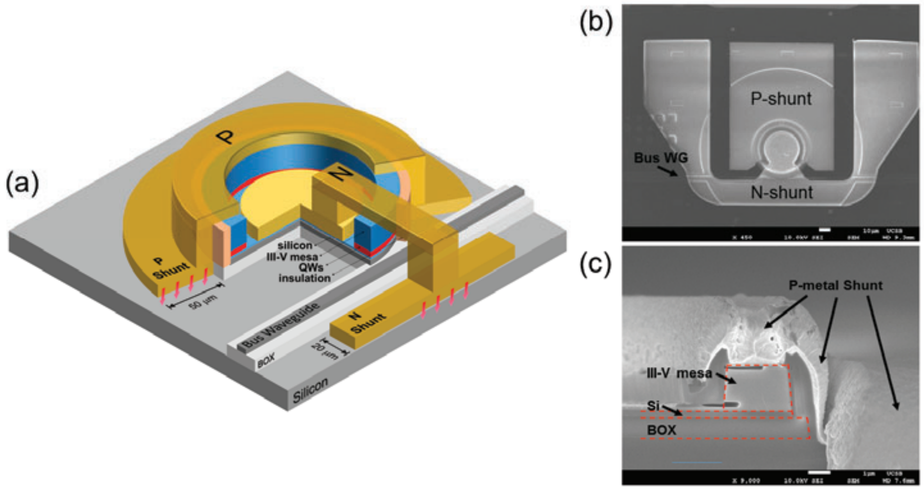

Fig. 1. (a) Illustration of hybrid silicon ring laser with thermal shunts; (b) plain-view and (c) cross-section view of a 50 μm ring laser

The devices were fabricated with a CMOS-compatible semiconductor process, including a low temperature hydrophilic bonding technique [4]. Fig. 1 (b) shows the plain-view SEM images of hybrid silicon ring laser with 50 μm diameter. The width of the metal shunt is about 50 μm for p and 20 μm for n. Fig. 1 (c) shows the cross-section view SEM image of the mesa with p-shunt. The total thickness of p-metal shunt is about 3 um which caps the entire III-V mesa, isolated from the QWs region with an 1 μm-wide insulation layer. In the end the SOI substrate was

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thinned down to 110 µm to further improve thermal transmission from device to heat sink. In order to clarify the improvement of thermal performance, we fabricated the same ring lasers without thermal shunts on the same chip.

3. Ring laser performance and discussions

Fig. 2 shows the light-current (L-I) curves with varying stage temperature for hybrid silicon ring lasers without and with the thermal shunt design. Both devices have low threshold current around 12.5 mA at 20 °C. However, the device without thermal shunt has a faster thermal rollover with temperature increases and only lase up to 70 °C. In contrast, the thermal shunted ring with same dimension has 10x higher output power and a maximum continuous-wave lasing temperature of 105 °C.

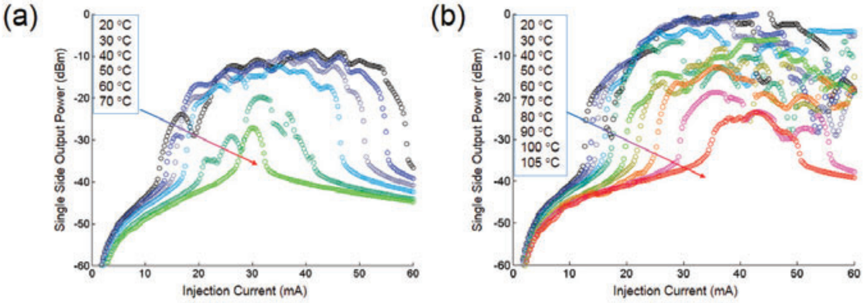

Fig. 2. LI curve of 50 µm ring lasers (a) without and (b) thermal shunt design

Fig. 3 (a) shows the device temperature evolution with injection current in a thermal reflection testing system. A couple of monitoring spots were chosen: center of n-metal (A, C) and on top of III-V mesa (B, D) as shown in top SEM images in Fig. 3(b). It's clear to see that ring without thermal shunt has more significant temperature increasing at the mesa top, which is about 70 K higher than the shunt design at about 95 mA injection. The thermal images in Fig. 3 (b) also provides clear evidence that the thermal shunts advance notably the heat dissipation from the mesa, which makes the laser ridge cooler than the one without shunt.

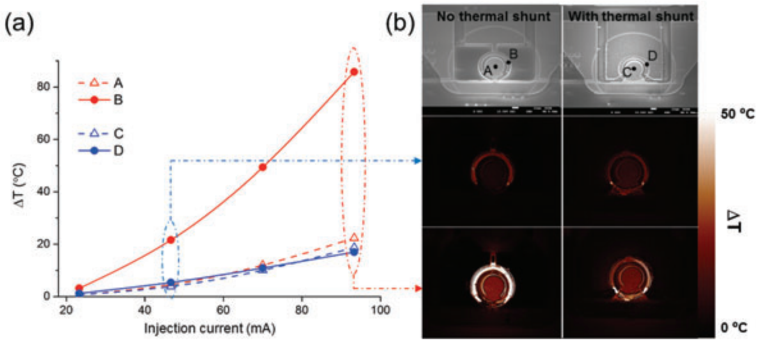

Fig. 3. (a) Temperature evolution with pulsed current injections at selected monitoring spots at ring laser with and without thermal shunts and (b) corresponding plain-view SEM images and thermal images with different injection current

4. Conclusions

We reported 50 µm diameter hybrid silicon ring lasers with novel thermal shunt designs that have a maximum continuous wave lasing temperature of 105 °C. This matches the operation temperature record of hybrid silicon lasers [5] with a more compact device dimension. This is important for hybrid silicon ring lasers to be used in interconnection applications in un-cooled ambiances, such as data centers.

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