InP-based ridge lasers with lateral n-contacts

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High-speed devices such as modulators and photodetectors on InP require the use of a semi-insulating substrate. Monolithically integrated lasers on semi-insulating substrates have to be provided with lateral n-contacts for current injection. In order to compare the performance of lateral n-contact with conventional back-side n-contacts, we fabricated ridge lasers on n-substrate that were provided with both lateral and backside n-contacts. In this article the performance of both types of contacts is compared.

Introduction

Monolithic integration of lasers and high speed devices on a semi-insulating (SI) substrate is a promising way toward high speed, reliable, small size and low cost modules for optical communication networks. One of the main issues in integration of these components is the use of a SI-substrate which provides a good electrical isolation of the components, reducing the parasitic capacitance, combined with the low RF-attenuation of the interconnections[1, 2].

In literature, two kinds of lateral n-contact Fabry-Perot lasers on SI-InP substrate are reported. Yu [3] described a grooved InGaAsP laser with a very low threshold current of 14 mA. Buried heterostructure (BH) lasers on SI-InP substrate were realized by Blondeau [4] to operate at 1.3 and 1.5 μm wavelength with a 3-dB modulation bandwidth of 15 GHz.

Current work concerns the realization and characterization of a Fabry-Perot ridge laser with both lateral and backside n-contacts. In this way we can compare the behaviour of the two types of contacts. We expect that the lateral n-contacts on SI-InP will behave in a similar way to those on the n-InP substrate. This article describes the fabrication of devices with lateral and backside n-contacts followed by the measurement results.

Device structure and fabrication

Figure 1-left shows a schematic structure of a deeply-etched ridge laser on n-InP substrate. The pin-diode ridge laser is formed by an epitaxial growth of the layers on a highly

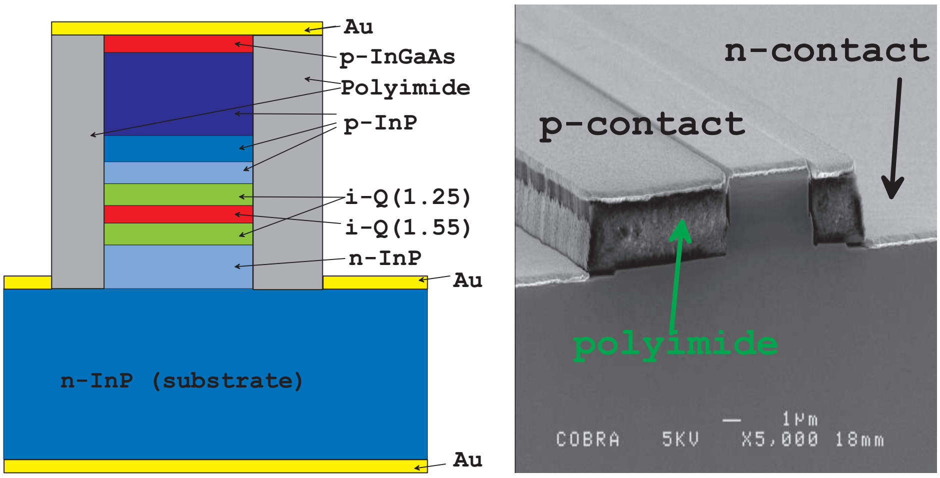

Figure 1: (left) Layer stack of lateral and n-contact ridge laser. (right) SEM photograph of the realized device.

n-doped (1-4 $\cdot 10^{18}$ /cm^3) InP substrate. The non-intentionally doped active layer is quaternary InGaAsP material with a bandgap wavelength of 1.55 μm ,Q(1.55) , and a thickness of 120 nm. The active layer is surrounded by two undoped confinement layers Q(1.25) with a thicknesses of 140 and 190 nm to decrease the barrier height and to establish the optical confinement. The p- and n-doped layers are InP material with a graded doping level to reduce the optical loss in the cladding layers and to make a low resistance path for electrons and holes. The buffer layer is an n-InP layer with a thickness of 500 nm and a doping level of $5 \cdot 10^{17}$ /cm^3 and the p-doped layers are graded with the doping levels of $1 \cdot 10^{17}$, $3 \cdot 10^{17}$, $5 \cdot 10^{17}$ and $1 \cdot 10^{18}$ /cm^3 for 50, 200, 300, and 1000 nm thicknesses, respectively. A highly p-doped InGaAs layer on top of the p-InP cladding layers significantly decreases the ohmic contact resistance. Two parallel end cleaved facets provide the mirrors of the cavity to establish the lasing operation.

The ridge lasers are fabricated on a chip that is epitaxially grown on n-InP substrate by using two masks. In the first step, the ridge p-mesa was etched by a RIE-machine by means of an optimized CH_4/H_2 etching followed by O_2 descumming by using a SiN mask. The etch depth is 100 nm below the buffer layer to make a good lateral n-contact. Then, polyimide was spun on the chip and processing followed by an etch back of the polyimide for exposing the p-contact layer. A photoresist mask was used to cover the p-contact regions, and subsequently the n-contact were opened by an etch back of the polyimide. Finally, Ti/Pt/Au was evaporated on the top and backside of the chip, so the ridge lasers can operate both with lateral and backside n-contacts. A SEM photograph of the fabricated device is presented in figure 1-right.

Characterization

Two main characteristics of the lasers are IV- and LI-curves which demonstrate the optical and electrical behaviour of the lasers. Figure 2 shows the setup that is used to characterize the ridge laser. The temperature of the copper chuck was controlled with a peltier element, a thermistor, and a thermo electric controller (TEC). The direct current was applied to the lasers via some probe needles: to apply a uniform current distribution, two needles for the p-contact and two needles for the lateral n-contact (depending on the device length) are utilized.

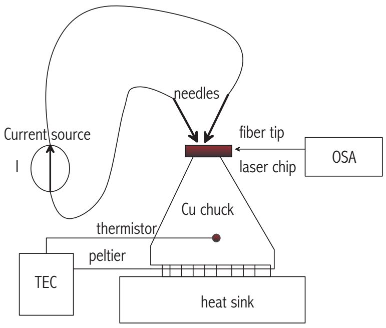

Figure 2: Measurement setup to characterize the ridge laser.

In figure 3, the LI and IV- curves of a ridge laser with a 1100 μm length and a 10 μm width are presented at 10, 20, 25, 30, 35, and 40 °C temperature for both lateral and backside n-contacts. It demonstrates that the optical output power, the threshold current, and the measured IV characteristics for both lateral and backside n-contacts are very close. Moreover, the optical output power saturates by increasing the bias current.

The IV-curves of the ridge laser for the positive voltages is fitted to equation: $I = I_s\left(\exp\left(\frac{eV}{nkT}-1\right)\right)$ where I_s is the saturation current, k is the Boltzmann's constant, T is the temperature (K), V denotes the applied bias voltage across the pn-junction, and n is a constant. To extract the series resistance from the measured IV-curve, an optimizing software is used [5]. The series resistance $R = R_d + R_s$, where R_d is the lead resistance and R_s is the series ohmic resistance of the ridge laser, and saturation current I_s and $\beta = e/(nkT)$ for the ridge laser with a length of 1150 μm and a width of 10 μm at 18 °C is determined which are $I_s = 4.6\cdot10^{-7}$ A, $\beta = 13.5$, and $R = 3\,\Omega$ for the lateral n-contact and $I_s = 1\cdot10^{-8}$ A, $\beta = 20$, and $R = 2.8\,\Omega$ for the backside n-contact. These values are of the same order of magnitude as the values mentioned in literature [6].

The threshold temperature coefficient, T_0, was determined by fitting the equation $I_{th} = I_0\exp(T/T_0)$ to the extracted threshold current from the measurement results (see figure 4-left). For both lateral and backside n-contacts, T_0=50 K was determined which is a typical value [6, 5].

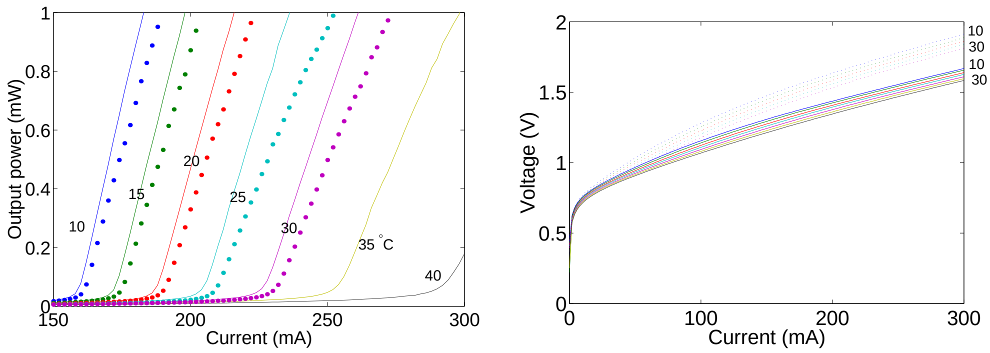

Figure 3: (left) The fiber-coupled optical output power for a ridge laser with 1100 μm length and 10 μm width for various temperatures. (right) IV-curve of the ridge laser for various temperature. The dotted lines show the measurements of the lateral n-contacts and the solid lines show the backside n-contacts.

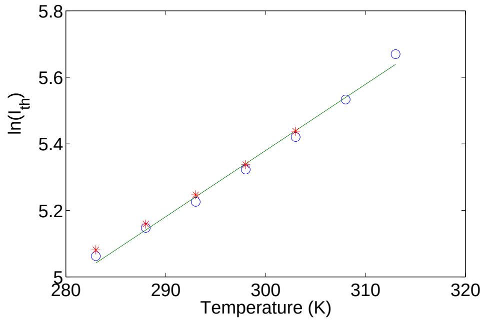

Figure 4: Threshold current versus temperature for lateral “⋆” and backside”○”and fitted curve ”solid”.

Conclusions

We have fabricated lateral n-contact ridge lasers on an n-InP substrate. The lasers show a behaviour almost identical to that of devices with a backside n-contact. So, we are confident that ridge lasers fabricated in a similar layer stack but grown on a SI-InP substrate, will function properly. The threshold current of the measured devices was higher than for conventional lasers due to non-perfect cleaving and/or non-optimal p-contact metalization. However, this doesn’t affect the comparison between the lateral and the backside n-contacts.

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