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First Demonstration of an Electrically Pumped Laser in the InP Membrane on Silicon Platform

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Abstract: We demonstrate the first electrically pumped laser in the “InP membrane on Si” platform. With pulsed current injection, the lasing occurs at threshold current of 200mA and peak optical power of 135µW in fiber.

OCIS codes: (140.5960) Semiconductor lasers; (250.3140) Integrated optoelectronic circuits

1. Introduction

The InP membrane on Si (IMOS) platform [1] is a novel candidate for resolving the on-chip data interconnect bottleneck. This platform consists of a thin III-V photonic membrane layer which can be placed on top of electronic chips, thereby allowing the integration of photonic and electronic functionalities. The major advantage of this platform is the ability to integrate active (lasers, photodetectors) and passive (waveguides, filters) components in a single III-V photonic membrane.

The key element in this platform is an optical amplifier or a laser with electrical pumping. In our previous report [2], we have presented the design and simulation of a novel design of a twin-guide amplifier structure in IMOS platform. The proposed amplifier structure has the advantages of reduced fabrication complexity and the ability of direct use as high-performance photodetector.

In this contribution we demonstrate for the first time lasing in an IMOS laser based on this twin-guide amplifier structure under pulsed current injection. We present the fabrication process of the IMOS lasers and the characterization results on the fabricated lasers.

2. Design and fabrication

The cross-section and the 3D view of the designed amplifier structure are depicted in Fig. 1 (a) and (b) respectively. The amplifier design consists of two vertically stacked waveguiding layers (250 nm Q1.58 and 300 nm InP) for the active and the passive functions respectively. The n-contact layers (100 nm thick, formed by an n+-doped quaternary layer (Q1.25) and an n-doped InP layer) are sandwiched between the active and passive waveguiding layers. The p-contact layers consist of a p-doped InP cladding layer; a p-contact region formed by quaternary spacer layers and highly p+-doped InGaAs. The entire layerstack is bonded to a SiO2/Si carrier wafer using BCB as the bonding material. The transition of the optical power from the amplifier and the passive waveguide is accomplished by a taper structure (see Fig. 1(b)) with short length (10 µm) and low loss (> 95% transmission). Light is coupled from the passive waveguides to optical fiber with a diffraction grating coupler [3].

![Fig. 1 (a) Cross section of the proposed SOA structure. Materials and dimensions are all indicated. (b) 3D schematic picture of the taper structure between SOA and waveguide.](image-url)

The fabrication process steps for the twin-guide amplifier structures as well as the passive waveguides and gratings are shown in Fig. 2. The fabrication starts with flip-chip BCB bonding of a designed III-V layerstack onto a SiO2/Si carrier wafer, followed by removing the InP substrate and the InGaAs sacrificial layer wet-chemically. After the bonding the amplifier patterns (including amplifier structures and tapers) are defined using electron beam lithography (EBL) with C60/ZEP mixed resist [4]. The addition of C60 significantly improves the thermal and chemical resistance
of the ZEP resist, and therefore improves the smoothness of the resist pattern. This pattern is transferred to the III-V layerstack with dry etching [5] up to the n-contact layer (Fig. 2(a)). The region for future n-type metal contact is defined with a second EBL. A layer of SiNₓ is used to protect the n-contact regions, while all the n-doped layers in all other regions are removed wet-chemically (Fig. 2(b)). Two more EBLs are performed to realize the passive waveguides and fiber-grating couplers with etch depths of 280nm and 120nm, respectively, as shown in Fig. 2(c). The entire sample is then covered with a 50-nm thin SiNₓ layer for electrical isolation and planarized with polyimide. Finally two lift-off processes with optical lithography are performed to create the p- and n-metal contacts, as shown in Fig. 2(d). The p- and n-metals are Ti/Pt/Au and Ni/Ge/Au respectively. A microscope picture of a fabricated ring laser is shown in Fig. 3.

Fig. 2 The fabrication process of the twin-guide amplifier structure. (a) First EBL for defining the amplifier structures on bonded sample. b) Second EBL for protecting the of n-contact regions. c) Third and fourth EBL steps for etching the passive waveguides and fiber-grating couplers. d) Lift-off step to create the p- and n- metal contacts.

Fig. 3 The fabricated ring laser with the twin-guide amplifier in the ring cavity.

3. Measurement

The measurement is performed on the ring laser as depicted in Fig. 3. The width and length of the amplifier section are 700 nm and 300 µm. The total cavity length of the ring is about 2 mm. The laser output is formed by a 2x2 multimode interference (MMI) coupler with 50/50 power splitting ratio. Two probe needles are used to contact the p- and n-metal contacts respectively and inject a pulsed current. The settings for the pulsed input are 50 ns pulse width and 1 % duty cycle. The light output is coupled into a vertically placed single-mode fiber through one of the fiber-grating couplers placed at both sides of the ring laser outputs.
The electrical characteristics of the amplifier diode are very good, showing around 15 Ω series resistance at forward bias and 20 nA dark current at -3 V reverse bias. The light-current (LI) characteristics of the laser is measured by scanning the peak current, and recording the optical power in a power meter, as shown in Fig. 4(a). It can be seen that the lasing threshold is around 200 mA peak injected current. This value is about 10 times higher than expected. This may be due to the underestimation of the optical losses in the metals, or the fabrication errors during the epitaxial growth and following processing steps. The maximum peak output power in fiber is about 135 µW (considering the 1% duty cycle). Considering a 6 dB fiber-grating coupling loss and bi-directional operation of the laser, the peak optical output power in waveguide is as high as 1 mW. The measured output spectra of the ring laser are shown in Fig. 4(b). The red curve corresponds to the amplified spontaneous emission (ASE) below threshold (150 mA), and the blue curve corresponds to the multimode lasing spectrum above threshold (600 mA). The zoom-in spectrum of the lasing modes is shown in Fig. 4(c). The multimode lasing behavior is mainly due to the fact that there is no spectral filter in the ring cavity for mode selection. The extinction ratio between the lasing modes and the ASE noise is about 20 dB.

![Graphs showing LI curve, output spectra, and zoom-in spectrum of the lasing modes.](image)

**Fig. 4** (a) The LI curve of the ring laser, (b) The output spectra of the ring laser below (in red) and above (in blue) threshold, (c) The zoom-in spectrum of the lasing modes.

4. Conclusion

We demonstrate in this contribution the first electrically pumped membrane laser in the IMOS platform. The laser has shown good electrical characteristics as well as high optical output power. Future works on the improvement of IMOS laser will focus on reducing the threshold and introducing an intra-cavity mode filter.

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