Monolithically integrated microring lasers in silicon nitride photonics

Jinfeng Mu, Meindert Dijkstra, and Sonia M. García-Blanco

Optical Sciences Group, MESA+ Institute for Nanotechnology, University of Twente, P.O. Box 217, 7500 AE Enschede, The Netherlands, e-mail: j.mu@utwente.nl

Light sources in integrated photonics circuits (PICs) are essential for many applications. In this work, Al_2O_3:Yb^{3+} microring lasers were monolithically integrated with the low-loss passive Si_3N4 platform. The active and passive waveguides are coupled through optimized tapers based on the double-layer photonic platform with high coupling efficiency and controlled overlay errors. Single-mode (SM) lasing has been realized in the 1.03 µm wavelength regime with output laser power up to -20 dBm. Such lasers yield the potential of monolithic active devices in the Si_3N_4 platform for diverse applications such as active biosensors, amplifiers and tunable lasers in different wavelength ranges by doping Al_2O_3 with different rare-earth-ions.

Introduction

The rapid development of integrated photonic technology increasingly demands to integrate various optical modules into compact cost-effective devices with high fabrication yield [1]. The integration of light sources such as lasers and amplifiers in Si_3N_4 platform remains an interesting research field. By using hybrid integration, lasers with emission from the visible to the near-infrared have been realized. Lasing in the visible spectrum was demonstrated both by bonding an organic dye-doped Poly(methyl methacrylate) (PMMA) cladding onto a Si_3N_4 spiral resonator [2] and by embedding colloidal quantum dots onto Si_3N_4 discs [3]. The most commonly used scheme is hybrid integration by which commercially available III-V semiconductor optical amplifiers (SOA) are combined with external Si_3N_4 cavities [4-9] by facet bonding (i.e., butt-coupling). World-record-performance for a narrow intrinsic linewidth hybrid laser (290 Hz) was realized by butt-coupling an InP SOA to a high Q external cavity on the Si_3N_4 platform [6].

The main advantage of this type of hybrid integration is that the SOA is commercially available, and high-performance devices can be independently fabricated on the Si_3N_4 platform. Good performance of the hybrid lasers requires careful optimization of the interface between the III-V and Si_3N_4 waveguides for butt-coupling [10]. Such assembly and packaging requires precise alignment accuracy, leading to difficulties in realizing large-scale, cost-effective and efficient processes, especially when scaling to PICs with complex functionalities and high integration density. Besides the above-mentioned lasers by hybrid integration, monolithic integration of rare-earth-ion doped materials and Si_3N_4 provides a promising alternative for high-performance and mass-manufacturable active devices. Many distributed Bragg reflectors (DBR) and distributed feedback (DFB) lasers have been developed by depositing the Al_2O_3:RE^{3+} layers directly onto the Si_3N_4 platform [11-16]. These DBR and DFB lasers have in common that the optical mode is guided in a ridge waveguide formed by several Si_3N_4 segments and a deposited Al_2O_3:RE^{3+} layer.

In this paper, we present monolithic Al_2O_3: Yb^{3+} microring (MRR) lasers integrated with Si_3N_4 wafer using our double-layer active-passive platform [17-19]. The Al_2O_3: Yb^{3+} active material was deposited by RF co-sputtering on thermally oxidized silicon wafers with 8 μm SiO_2 thickness. The Al_2O_3:Yb^{3+} and Si_3N_4 waveguides are coupled through vertical tapers with measured coupling loss below 0.5 dB. The lasers were optically pumped at the wavelength of 975.5 nm through the Si_3N_4 waveguide. Single-mode (SM) lasing has been achieved at wavelengths between 1010 nm to 1045 nm for multiple laser chips with output powers of several µWatts.

Results

The integrated Al_2O_3:Yb^{3+}-Si_3N_4 lasers are based on the double-layer monolithic platform proposed in our previous work [17-19]. A 200 nm thick Si_3N_4 single strip waveguide on a ~8 µm thick thermally-oxidized Si is employed. Both fundamental TE modes of the pump (975.5 nm) and laser lights (1010–1045 nm) were coupled through a vertical coupler that consists of an Al_2O_3 waveguide with tapered width from 1.4 µm to 0.8 µm, and an Si_3N_4 taper with tapered thickness from 200 nm to ~10 nm, as shown in Fig.1(a), allowing the transferring of both modes with low-loss between the Al_2O_3:Yb^{3+} and Si_3N_4 waveguides. Both tapers have a length of 220 µm and a width of 1.4 µm. The Si_3N_4 vertical tapers were fabricated using wet-etching technique with a PECVD SiO_2 as sacrificial layer. Between the Al_2O_3:Yb^{3+} and Si_3N_4 waveguides, there is a thin LPCVD SiO_2 film with a thickness of 60 nm after CMP polishing. This thin film not only separates the Si_3N_4 and Al_2O_3:Yb^{3+} layers but also protects the Si_3N_4 surface during the fully etching of the Al_2O_3:Yb^{3+} waveguides. The laser layout is shown in Fig.1 (b), where the Al_2O_3:Yb^{3+} MRR has a width of 1.4 µm, a radius of 300 µm and a gap distance of 1 µm between the bus waveguide and the ring.

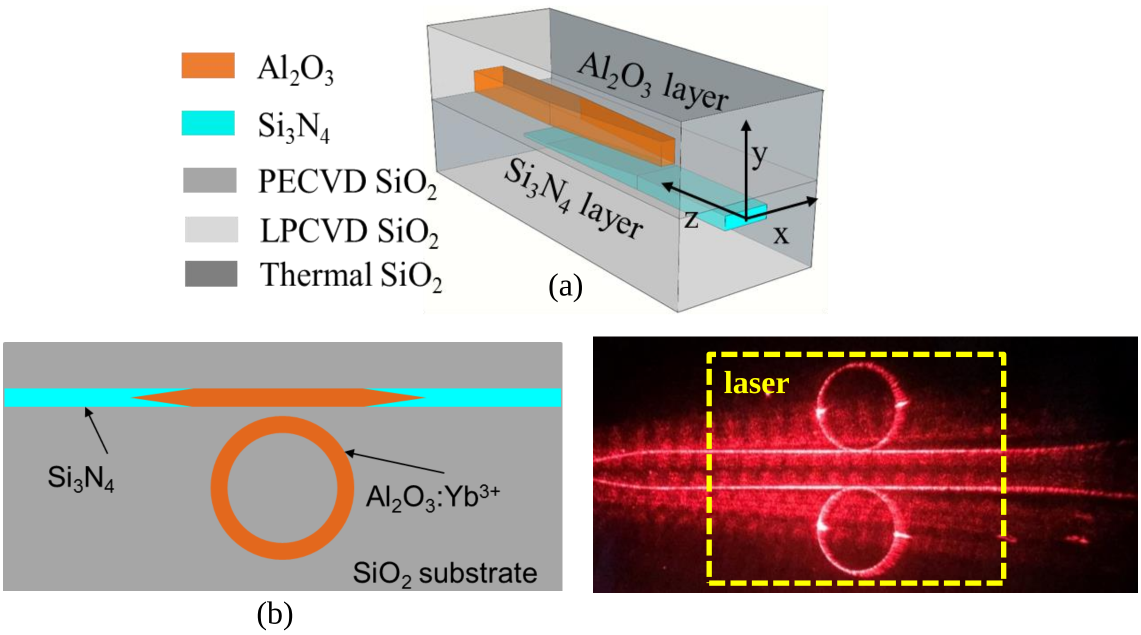

Fig. 1. (a) 3D schematic of the vertical coupling region [17] and 2D schematic of the integrated Al_2O_3:Yb^{3+} microring laser in the Si_3N_4 platform with tapered waveguides in the vertical coupling region. (b) Mask layout of the integrated lasers, with integrated 3 dB 975.5 nm pump power splitter, and its optical image aligned using the red light laser.

To fabricate the lasers, similar processes as reported earlier [18-20] were used for the Si_3N_4 and Al_2O_3:Yb^{3+} waveguides. The characterization setup of these lasers is demonstrated in Fig. 2(a). The chip is optically pumped by a 975.5 nm diode. The pump light is launched into the chip through a 980/1060 wavelength division multiplexer (WDM). The MRR laser has both clockwise and counter-clockwise modes. One of the lasing modes is collected at the input port and then is split from the pump light by the WDM. An optical spectrum analyzer (OSA) is employed to detect laser spectrums. Fig. 2(b) shows the spectra from 9 different MRR lasers at the pump power of ~30 mW (diode output). The highest output power measured is about 10 μW in this preliminary experiment, indicating the feasibility of lasing based on this monolithic integration scheme.

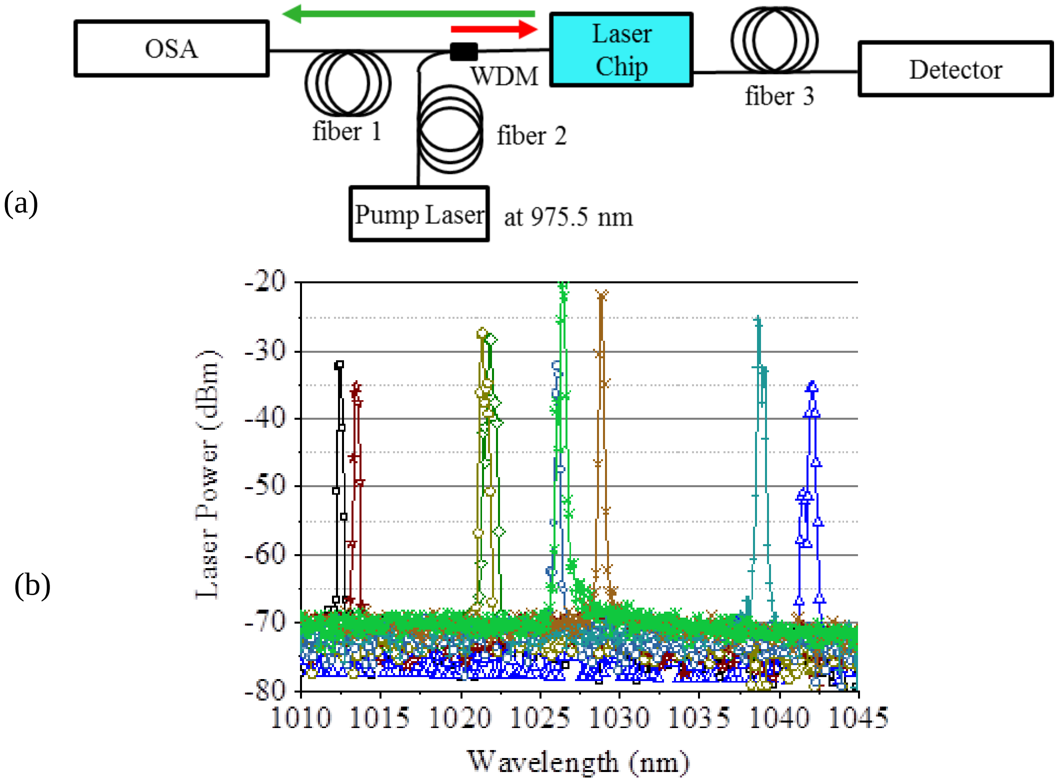

Fig. 2. (a) Schematic of the experiment setup based on fibers. The lasers are optically pumped using an external diode at 975.5 nm wavelength. (b) Measured lasing peaks near the peak emission of Yb^{3+} at the wavelength of 1030 nm, including a schematic of the integrated Al_2O_3:Yb^{3+}-Si_3N_4 microring (MRR) laser. Different colors indicate that the measurements are from different integrated MRR lasers.

Conclusion

We demonstrated monolithically integrated Al_2O_3:Yb^{3+}-Si_3N_4 lasers based on a double-layer platform with μW output power. It provides a promising way towards the realization of active functionalities on the Si_3N_4 platform using rare-earth-ion doped Al_2O_3 material. Experiments are being carried out to characterize more laser specifications.

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