Recent progress on rare earth amplifiers and lasers directly on silicon

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Silicon has become the platform of choice for low-cost, energy efficient and high-speed photonic microsystems for applications ranging from communications to healthcare. However, the development of on-chip amplifiers and lasers has been one of the persistent challenges in silicon photonics. Silicon itself is an inefficient light emitting material, which has led to various approaches to integrate different gain media on Si [1]. Much of these efforts have focused on heterogeneous or monolithic integration of III-V semiconductors leading to effective electrically pumped commercial devices [2]. However, optically pumped rare earth gain media can be considered an attractive alternative for many emerging applications, motivated by their low-cost, monolithic wafer scale deposition methods, broadband emission at near-infrared wavelengths of interest, and potential for low noise amplification and narrow-linewidth lasing [3]. However, integrating rare-earth amplifiers and lasers directly on silicon has proven challenging for several reasons, including the high confinement and relatively high loss in silicon waveguides making it difficult to achieve net optical gain, and incompatibilities with silicon photonic manufacturing (e.g., due to high temperatures required for deposition of rare-earth-doped gain materials).

Here we report on our recent developments on rare-earth-based gain and lasing directly on silicon photonic chips. We demonstrate optical gain and on-chip lasing around 1.8—1.9 μm in thulium-doped tellurium oxide (TeO_2:Tm^{3+}) coated silicon hybrid microdisks [4]. The silicon photonic chips are fabricated using a standard silicon foundry process, while the TeO_2:Tm^{3+} film is deposited at room temperature using a straightforward reactive RF magnetron co-sputtering post-processing step. We show lasing at 1.9 μm with a double-sided on-chip output power of > 1 mW, threshold launched pump power of 16 mW, and slope efficiency vs. absorbed pump power of 60% in point-coupled microdisks (Fig. 1a). We also demonstrate net optical gain within the hybrid TeO_2:Tm^{3+}-Si bus waveguide. In addition, we show sub-milliwatt threshold lasing in pulley-coupled microdisks which are engineered for stronger pump and reduced signal coupling strength (Fig. 1b). These results demonstrate the possibility of wafer-scale integration of thulium amplifiers and lasers in silicon photonic circuits for emerging applications near 2 μm. In addition, they provide motivation for exploring other dielectric gain materials, dopants and emission wavelengths (e.g., Er and 1.5 μm), and the development of novel monolithic devices and circuits (e.g., amplified silicon delay lines and tunable rare earth lasers) for applications in communications, computing, and sensing.

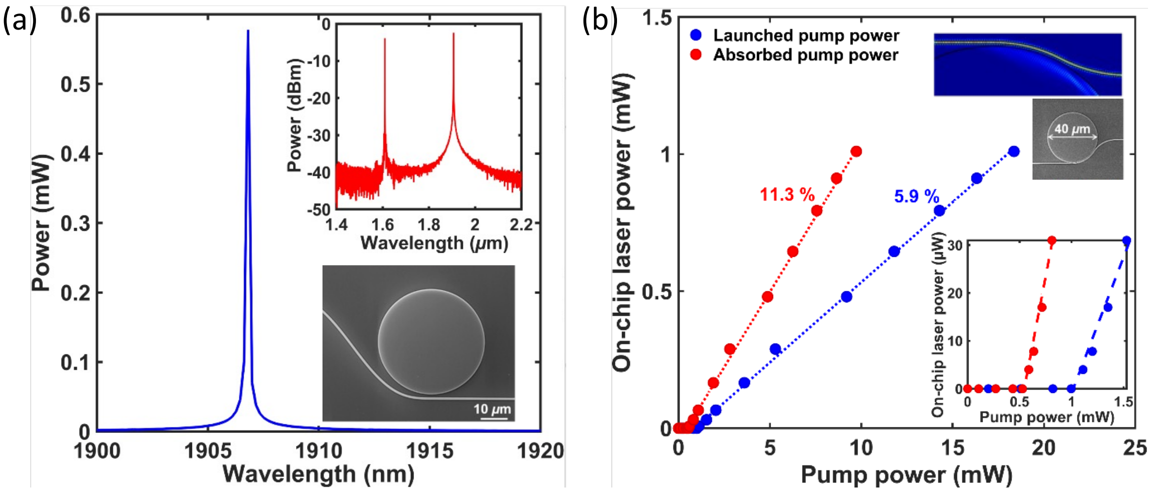

Fig. 1 (a) On-chip laser emission at 1.9 μm demonstrated in a hybrid TeO_2:Tm^{3+}-silicon microdisk (insets: broader spectrum showing residual 1.6-μm pump and laser signal light collected at chip output and top-view SEM of microdisk laser). (b) Sub-milliwatt-threshold lasing using a pulley-coupled microdisk design (insets: simulation of pulley coupled bus waveguide to engineer pump and signal coupling to and from the microdisk, respectively, SEM of pulley-coupled microdisk laser, and zoomed-in view of the laser curve near threshold).

References

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