Rare-earth-ion-doped materials and resonant structures for active integrated optics

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Despite the fact that silicon has advanced as a highly promising material for densely integrated optical circuits, which also opens routes for electronic-photonic integration, the lack of optical gain in this material is a major disadvantage. Since integration of epitaxially grown materials with optical gain such as III-V semiconductors or rare-earth-ion-doped crystalline materials onto a silicon chip is currently not possible, hybrid integration via bonding, gluing, or other methods is investigated.

We follow an alternative route by rare-earth-ion doping of materials which can be deposited on a silicon chip in thin-layer geometry by non-epitaxial methods. Although the gain which can be achieved in rare-earth-ion-doped bulk materials is typically two orders of magnitude smaller than in semiconductor lasers and amplifiers, the strong confinement of pump and signal light in channel waveguide geometry can enhance the gain by an order of magnitude and make these materials suitable for producing optical gain on a silicon chip. The materials we have been investigating include $Al_2O_3:Er^{3+}$ and fluorinated epoxy waveguides doped with Nd^{3+} nano-complexes. In the former material sputtered onto thermally oxidized Si wafers, we have achieved net optical gain on the transition $^4I_{13/2} \rightarrow {}^4I_{15/2}$ with a maximum of 0.76 dB/cm at 1533 nm and gain bandwidth of 35 nm [1]. The latter material exhibits enhanced luminescence under pumping near 800 nm [2], and investigations to achieve net optical gain on the transitions $^4F_{3/2} \rightarrow {}^4I_{11/2}$ near 1060 nm and $^4F_{3/2} \rightarrow {}^4I_{9/2}$ near 900 nm are currently under investigation.

Bragg grating structures for the reflection of near-infrared or visible light, which are often employed as resonant structures in fiber lasers, are difficult to produce with sufficient accuracy and low loss to form an on-chip laser cavity in the aforementioned materials. While deep reactive ion etching is well developed for silicon-based materials, similar processes do not deliver the necessary resolution of a few 100 nm in these materials. Focused ion beam etching is an alternative method to obtain acceptable structures, albeit in a serial, timeconsuming, and expensive additional processing step. Ring resonators are a useful means to build densely integrated on-chip resonant structures [3] and they present a viable alternative for achieving gain in rare-earth-ion-doped waveguides [4]. We are currently testing such structures for demonstrating silicon-chip-based lasers in Al_2O_3:RE layers.

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