Low-Threshold, Single-Frequency Distributed-Feedback Waveguide Laser in $Al_2O_3:Er^{3+}$ on Silicon

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Abstract: Single-frequency distributed-feedback lasing with 165 μW output power at 1538.8 nm is realized in $Al_2O_3:Er^{3+}$ waveguides fabricated on silicon wafers. Distributed feedback is provided by a surface relief Bragg grating fabricated with laser interference lithography.

OCIS codes: (140.3460) Lasers; (140.3500) Lasers, erbium; (140.3490) Lasers, distributed-feedback

1. Introduction

The implementation of dense wavelength division multiplexing (DWDM) in telecommunication networks has greatly encouraged the development of stable single-frequency light sources. Rare-earth-ion-doped distributed feedback (DFB) dielectric lasers are of particular interest for this purpose due to their stable, single-mode, single-polarization, narrow-linewidth and low-noise emission [1, 2].

Erbium-doped aluminum oxide ($Al_2O_3:Er^{3+}$) has been identified as a promising laser gain medium due to its optical properties, which include low background losses and an internal optical gain over the entire telecommunication C-band (1525-1565 nm) with a peak gain as high as 2.0 dB/cm [3]. The relatively high refractive index of 1.65, which permits the fabrication of small optical structures, and the compatibility with silicon substrates further highlight $Al_2O_3:Er^{3+}$ as a favorable gain medium for telecommunication optical networks. Very recently the first monolithic laser in $Al_2O_3:Er^{3+}$ was demonstrated in a ring resonator geometry [4].

In this work we present the first single-frequency monolithic distributed feedback (DFB) waveguide laser in $Al_2O_3:Er^{3+}$. Its output power surpasses that of the previously demonstrated ring laser by more than one order of magnitude while providing the additional feature of single-frequency operation.

2. Fabrication

$Al_2O_3:Er^{3+}$ layers with a thickness of 1 μm were deposited onto standard thermally oxidized silicon wafers [5]. The erbium doping concentration is $\sim 1\times10^{20}$ cm^{-3}. One-centimeter-long ridge waveguides with an etch depth of 100 nm and a width of 3 μm were etched into the layers via reactive ion etching [6]. In order to ensure single longitudinal mode behavior, a distributed quarter-wave phase-shift is introduced to the cavity by means of a 2-mm-long adiabatic tapering of the waveguide width in the center of the cavity. A 700-nm-thick plasma-enhanced chemical vapor deposition SiO_2 cladding layer was deposited on top of the waveguides. The grating pattern was defined in a negative resist layer on top of the SiO_2 by means of laser interference lithography. Finally the grating pattern was etched into the SiO_2 layer using a $CHF_3:O_2$ reactive ion plasma. The resultant Bragg gratings have an etch depth of ~150 nm with a period of 489 nm and a duty cycle of ~ 50%.

3. Characterization

The experimental setup that was used to characterize the laser is shown in Fig. 1. The laser was optically pumped with a 976 nm laser diode where a maximum pump power of 83 mW was launched into the waveguide. The power characteristics of the laser is shown in Fig. 2a. The laser emission was collected from the pumped side of the cavity via a wavelength division multiplexing (WDM) fiber and sent to a power meter.

The DFB laser threshold occurs at a launched pump power of 20 mW. The maximum laser emission from the pumped side of the cavity is 165 μW, which results in a slope efficiency of 0.25% versus launched pump power. Since only approximately 25% of the launched pump power is absorbed, a threshold of 5 mW and slope efficiency of 1% are derived versus absorbed pump power. Compared to previous results [1,2] these performance data emphasize the strong light confinement due to the comparatively high refractive index of Al_2O_3. Since characterization of the Bragg gratings showed that the Bragg reflection of the TM mode occurs at ~1527 nm, we conclude that the laser was operating TE-polarized at all times.

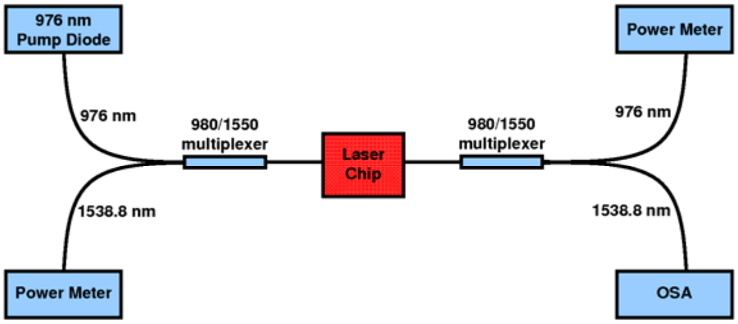
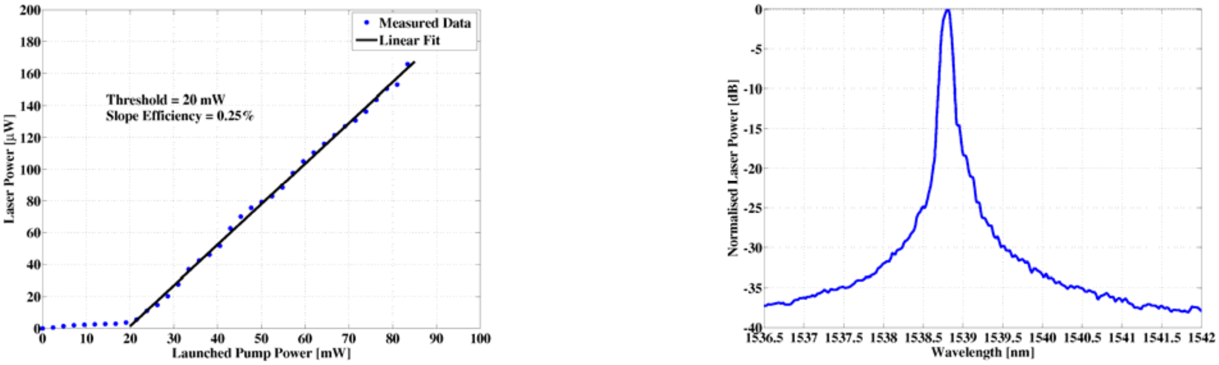


Fig. 1. Experimental setup used to characterize the DFB laser

The laser emission from the unpumped side of the cavity was collected with a WDM fiber and sent to an optical spectrum analyzer (OSA) with a resolution of 0.1 nm. The laser operated at a wavelength of 1538.8 nm and exhibits a side-mode suppression ratio of more than 35 dB (see Fig. 2b). Although single-mode behavior could be confirmed with this measurement, the linewidth of the laser emission was limited by the resolution of the OSA. Higher resolution heterodyning measurements in order to determine the linewidth are currently being conducted.



(a) (b)

Fig. 2. (a) Laser output power of the DFB laser as a function of launched pump power; (b) normalized laser emission spectrum measured with an optical spectrum analyzer with a resolution of 0.1 nm

4. Conclusion

The first monolithic distributed-feedback waveguide laser in $Al_2O_3:Er^{3+}$ was presented. The laser operated in a single-longitudinal-mode and single polarization (TE) where a maximum output power of 165 µW was achieved. To the best of our knowledge, this is the first rare-earth-ion-doped DFB laser that is fabricated on a silicon substrate. This result holds many promising opportunities for the integration of such single-frequency lasers with existing dielectric waveguide technology on silicon substrates.

Funding was provided by the Smartmix Memphis programme of the Dutch Ministry of Economic Affairs.

5. References

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