High Temperature Operation of an Integrated Erbium-Doped DBR Laser on an Ultra-Low-Loss Si_3N_4 Platform

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Abstract: We demonstrate record high temperature operation, 400 °C, of an integrated $Al_2O_3:Er^{3+}$ DBR laser on an ultra-low-loss Si_3N_4 waveguide platform. Additionally, the device exhibits an uncompensated temperature dependent wavelength shift of 1.92 GHz/°C and maintains over 1.5 mW of output power throughout the entire temperature range.

OCIS codes: (130.3120) Integrated optics devices; (140.3500) Lasers, erbium; (230.1480) Optical devices, Bragg reflectors.

1. Introduction

Meeting currently forecasted demands for future telecommunications and environmental sensor system design requires optical sources that are not only able to successfully operate at elevated temperatures, but at the same time retain a high degree of wavelength stability while doing so. Traditionally, such constraints have only been met though the use of fiber-based devices, which are capable of operating throughout an extreme temperate range, while at the same time exhibiting a minimal shift in operating wavelength [1]. Such designs come at a premium in cost though, as the fiber gratings must be first written through a femtosecond laser inscription process. Considerable physical space margins must also be allowed, as fiber-based components are typically much larger than their on-chip equivalents. Future continued system scaling within this domain thus necessitates an integrated solution. Recently, we have demonstrated an ultra-low-loss Si_3N_4 waveguide platform capable of not only integrated waveguide sidewall Bragg gratings [2], but also erbium-doped distributed Bragg reflector (DBR) and distributed feedback (DFB) laser arrays utilizing the sidewall grating framework [3]. In this paper, we report record high temperature on-chip lasing from a DBR device at stage temperatures up to 400 °C (the limit of our measurement setup). To date such environmental robustness has not been achieved by any other reported photonic integrated circuit (PIC) technology. Additionally, the device exhibits an uncompensated temperature dependent laser output wavelength shift of 1.92 GHz/°C (15.61 pm/°C) and maintains an output power above 1.5 mW over the entire temperature range.

2. Design and Fabrication

A cross-section schematic of the waveguide structure is shown in Fig. 1. (a). Fabrication of the device began on a 100 mm silicon substrate, upon which 15 μm of thermal SiO_2 lower cladding was grown. An 80 nm (t_1) low-pressure chemical vapor deposition (LPCVD) Si_3N_4 guiding layer was then deposited and patterned using a dry etch procedure. The nominal waveguide width (w) used in the cavity design was 2.8 μm. Figure 1. (b) illustrates a top-down schematic of the resonator, including the high and low reflectivity mirrors (L_1 and L_2 of 1.5 mm, respectively), and the 17 mm (L_{cavity}) straight waveguide section. The 100 nm SiO_2 spacer layer and the 1.67 μm (t_2) $Al_2O_3:Er^{3+}$ gain layer were then deposited by a reactive co-sputtering process. This design assures minimal waveguide scattering losses, as well as a high confinement factor in the active medium for both the pump and signal wavelengths. Further details of the device fabrication and design are reported in [2].

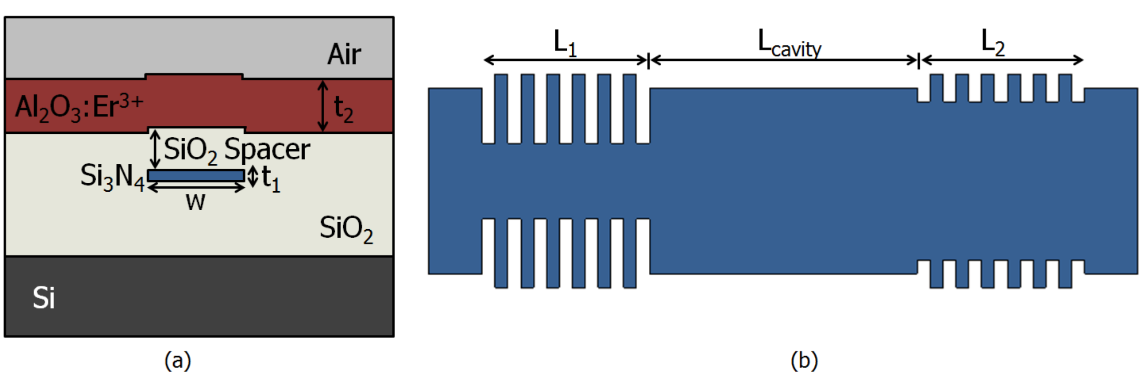

Fig. 1. (a) Cross-section schematic of the waveguide design. (b) Top-down schematic of the Si_3N_4 waveguide structure.

3. Device Characterization

During testing the entire device die was placed on a hotplate with a maximum operating temperature of 400 ^{o}C. The DBR laser was optically pumped from a single facet using a 974 nm laser diode and a 980/1550 nm fiber wavelength division multiplexer. Figure 2. (a) shows that at a room temperature of 20.9 ^{o}C the laser exhibits a threshold pump power of 11 mW and a pump-to-signal conversion efficiency (η) of 5.2%. With the hotplate adjusted to its maximum operating point of 400 ^{o}C the laser emission has decreased by less than 2 dB, and we are still able to achieve more than 1.5 mW of output power. Here the threshold pump power has increased to 15 mW and the efficiency (η) has decreased to 4.0%. We attribute the small change in output power over such a wide temperature range to our choice of pumping the device with 980 nm light, as opposed to 1480 nm light [4]. Figure 2. (b) gives the optical spectra of the device when operating at the previous two temperatures. The device exhibits a minimal redshift with increasing temperature, as the output at 20.9 ^{o}C is centered at 1560.2 nm and the output at 400 ^{o}C is centered at 1566.2 nm.

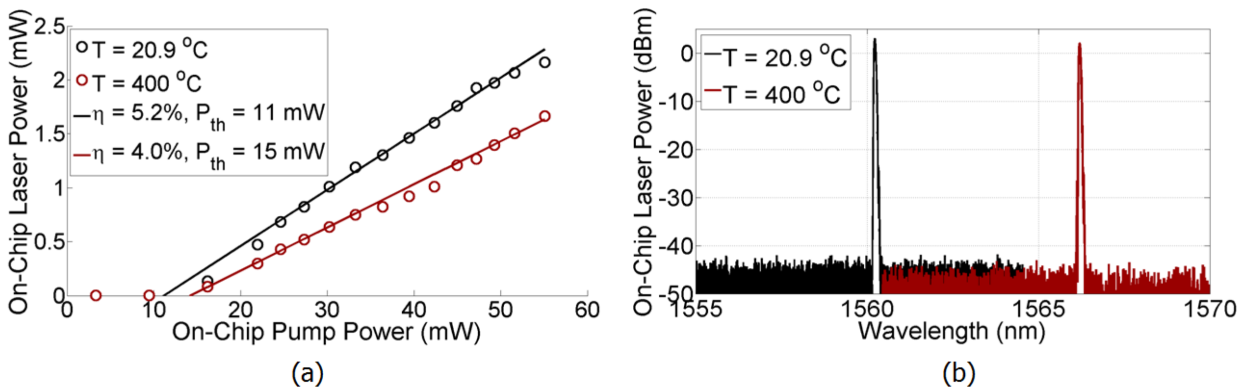

Fig. 2. (a) DBR laser power as a function of launched pump power for the device operating at two different temperatures. (b) Optical spectrum of the device at the same two previous temperatures.

A finer measurement of the lasing wavelength shift as a function of temperature is shown in Fig. 3. Here we achieve a near-linear lasing wavelength shift with temperature of 1.92 GHz/^{o}C (15.61 pm/^{o}C).

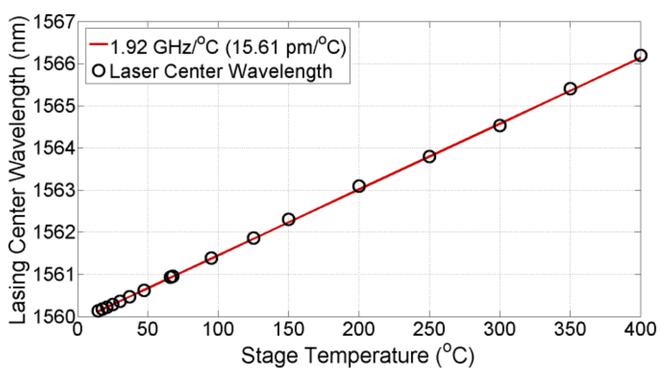

Fig. 3. Characterization of the frequency shift of the device across the operating temperature range.

Tables 1 and 2 compare our $Al_2O_3:Er^{3+}$ on ULLW results with other on-chip platforms presented in the literature.

Table 1. Highest reported operating temperature for different on-chip devices and integration platforms.

Laser Type	Highest Reported Operating Temperature (^{o}C)	Reference
$Al_2O_3:Er^{3+}$ on ULLW	400	This work
Hybrid Si	119	5
Quantum Well	220	6
Quantum Dot	161	7
VCSEL	134	8

Table 2. Lowest reported uncompensated lasing wavelength shift with temperature for different on-chip devices and integration platforms.

Laser Type	Lasing Wavelength (nm)	Best Reported Slope (GHz/C)	Reference
$Al_2O_3:Er^{3+}$ on ULLW	1560	1.92	This work
Hybrid Si	1330	11.10	9
Quantum Well	499	67.42	10
Quantum Dot	1020	13.08	11
VCSEL	1000	18.88	12

4. Conclusion

We have demonstrated record high temperature on-chip lasing from an erbium-doped waveguide DBR device at stage temperatures up to 400 ^{o}C. The device output exceeds 1.5 mW of power at all measured temperatures. The device characterized also exhibits an uncompensated temperature dependent laser output wavelength shift of 1.92 GHz/^{o}C.

Acknowledgements

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