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Integrated DFB Lasers on Si_3N_4 Photonic Platform for Chip-Scale Atomic Systems

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Abstract: 780 nm wavelength distributed feedback lasers have been integrated onto a Si_3N_4 photonic platform on a Si substrate and coupled into waveguides for laser locking to either a ring resonator or rubidium vacuum cell.

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1. Introduction

Atomic transitions using warm gases of rubidium (Rb) or cesium (Cs) atoms have been used to produce chip-scale atomic clocks [1] and magnetometers for timing and magnetoencephalography applications [2] respectively. At present these chip-based atomic systems use VCSELs pumping a micro-electro-mechanical system (MEMS) cell fabricated cavity full of Rb or Cs gas [1]. These systems require precise lasers with narrow line-widths that can be locked to the specific atomic transition frequency of interest enabling the excitation from an atomic ground state to a higher state and the optical transmission at the same wavelength allows the measurement of the population of electrons in the clock states of the atoms. The ^{87}Rb absorption line at 780.24 nm wavelength is one of the key clock transitions but also through Doppler cooling, and optical molasses techniques would also allow cold atoms to be produced [3]. To build an integrated single chip system requires lasers combined with active and passive optical components. A suitable candidate for both is distributed feedback lasers (DFB), and the Si_3N_4 photonic integrated platform since both have demonstrated excellent performance at visible wavelengths. In this paper, we demonstrate the integration of a DFB laser on-chip by flip-chip bonding, which is coupled into Si_3N_4 waveguides and stabilized by locking to either a micro-ring resonator or an integrated MEMS cell with Rb vapor.

2. DFB and Si_3N_4 Waveguide Integration

The DFB lasers used for flip-chip bonding consists of an AlGaAs active region. These single mode lasers have demonstrated linewidths <10 MHz and output powers up to 30 mW at 780 nm wavelength [4]. The waveguides are fabricated from a 200-nm thick low-pressure chemical vapor deposition of Si_3N_4 at 750 ºC. The Si_3N_4 is deposited onto a 4 μm thick thermal SiO_2 layer grown by wet oxidation at 1000 ºC. To efficiently couple light from the DFB laser to the Si_3N_4 waveguides requires a spot-size converter (SSC). The SSC consists of a polymer that has a higher refractive index (~1.58) compared to the SiO_2 and thus allows guiding. The SSC has been designed so that it can provide ~ 80 % coupling depending upon the alignment of the DFB. To help improve alignment the DFB ridge is aligned to a patterned Au bond pad (see Fig. 1 (left)). This bond pad provides the top contact electrical access and thermal heat sinking of the DFB.

3. Light-Current-Voltage Characteristics of Integrated DFB laser

Light-current-voltage characteristics of the DFB laser before and after bonding has been measured at different operating temperatures (10-40 ºC). There is a clear red shift to a higher threshold current after flip-chipping (see Fig. 1 (right)). This is due to the reduced electrical and thermal contact between the DFB and bond pads. The DFB lasers on-chip, still produce ~10 mW of output power at a driving current of 120 mA at room temperature. This power level is sufficient for interrogating and locking to either a Si_3N_4 micro-ring resonance or a Rb atomic transition.

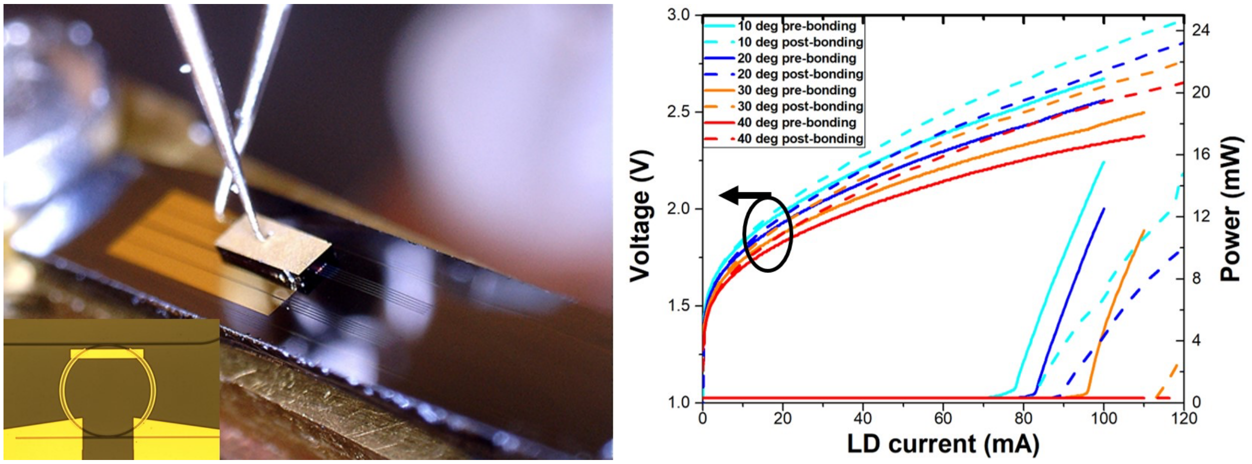

Fig. 1. (Left) An image of a DFB laser flip-chipped onto a Si substrate and coupled to Si_3N_4 waveguides by a spot size converter. The inset shows a Si_3N_4 ring resonator with integrated tuning heaters. (right) The LIV characteristics of the DFB laser before and after flip-chip bonding on top of the Si substrate.

4. Si_3N_4 Ring Resonator and Rubidium Integrated Vacuum Cell

The DFB laser can be stabilized by locking to a resonance of a micro-ring resonator by utilizing the Pound-Drever-Hall technique. Si_3N_4 ring resonators were fabricated with the waveguides that are used to couple from the DFB acting as the bus. The highest Qs that have been measured are ~1 M (see Fig.2 (left)). This approach has the advantage for locking the laser to wavelengths where atomic transitions are not available. For direct locking to an atomic transition the integration of a Rb MEMS cell would be advantageous. Therefore, we have investigated the integration of a Rb MEMS cell that allows locking through absorption spectroscopy (see Fig. 2 (right)).

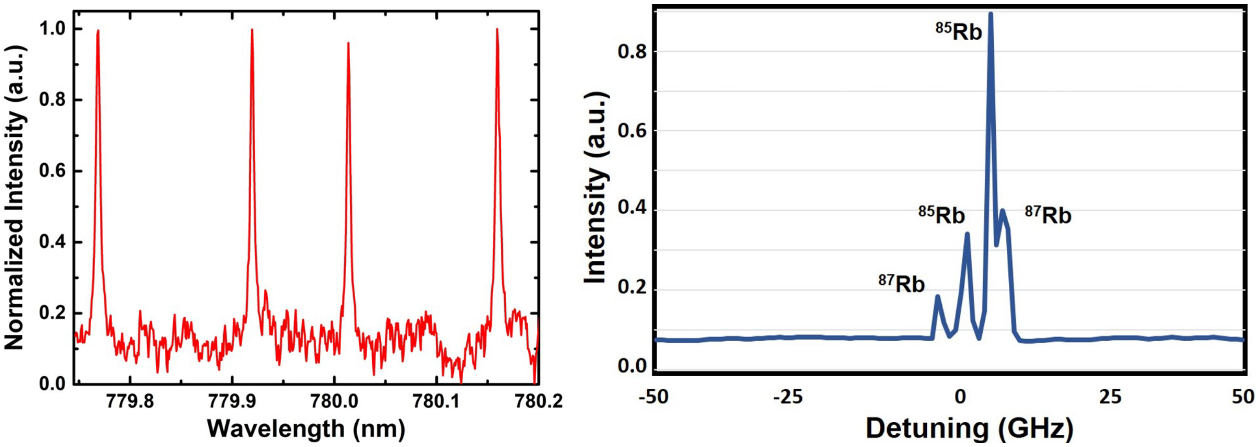

Fig. 2. (left) Transmission spectra of a 250 μm radius Si_3N_4 micro-ring resonator. (right) Spectra of the Rb absorption lines from a vapor cell.

5. Conclusion

DFB lasers operating at 780 nm wavelength have been bonded onto Si substrates and integrated with Si_3N_4 waveguides. The DFB laser is coupled to the Si_3N_4 waveguides by a SSC that can provide high coupling efficiency. In addition, Si_3N_4 ring resonators have been fabricated and characterized to provide a method for laser stabilization by using the Pound-Drever-Hall technique. As an alternative Rb MEMS cells have also been investigated for frequency locking the DFB to one of the Rb atomic transitions.

6. References

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