Narrow Linewidth Distributed Feedback Diode Lasers for Cooling in Cold Atom Systems

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Abstract: Distributed feedback (DFB) lasers have been realized emitting at a wavelength of 780.24 nm which demonstrate powers in excess of 60 mW with 612 kHz linewidth for use in rubidium (^{87}Rb) cold atom systems.

1. Introduction

There is an increasing requirement for chip scale atomic devices which rely on atomic transitions for high accuracy atomic clocks, magnetometers, gravimeters and navigators [1]. Where cold atoms are used, for example to provide higher accuracy for atomic clocks, the systems make use of large, expensive lasers which are power-hungry and frequency doubled lasers are required to achieve certain wavelengths. The lasers for cooling are required to have very narrow linewidths (< 1 MHz) to target specific atomic transitions, such as the ^{87}Rb absorption line at 780.24 nm [2]. Distributed feedback (DFB) diode lasers are ideal for miniature systems as the lasers can be a few mm long [2] with narrow linewidths [3] and can be integrated with Si_3N_4 photonics for chip scale systems [4]. In this work, 4 mm long distributed feedback (DFB) lasers have been fabricated emitting at 780.24 nm with power levels > 60 mW, linewidths of 612 kHz with a high side-mode suppression ratio of > 40 dBm (SMSR).

2. DFB Laser Fabrication

The DFB lasers were fabricated on a two-quantum-well GaAs/AlGaAs wafer material using an epilayer structure which was optimized for high-power applications and included a far-field reduction layer to improve the optical coupling into optical fibres [2]. The DFB gratings were patterned using a hydrogen silsesquioxane (HSQ) mask by electron beam lithography (EBL) and etched using chlorine dry etching (Fig. 1(a)). The samples were covered with a SiO_2 passivation layer, and only a narrow window was etched to allow the top contact evaporation. The top (Ti/Pt/Au) and bottom (Au/Ge/Ni) contacts were evaporated after the sample was thinned down to a thickness of 250 μm. Finally, the sample was cleaved in bars and the bars mounted on brass supports to ensure good thermal and electric conductivity to the laser.

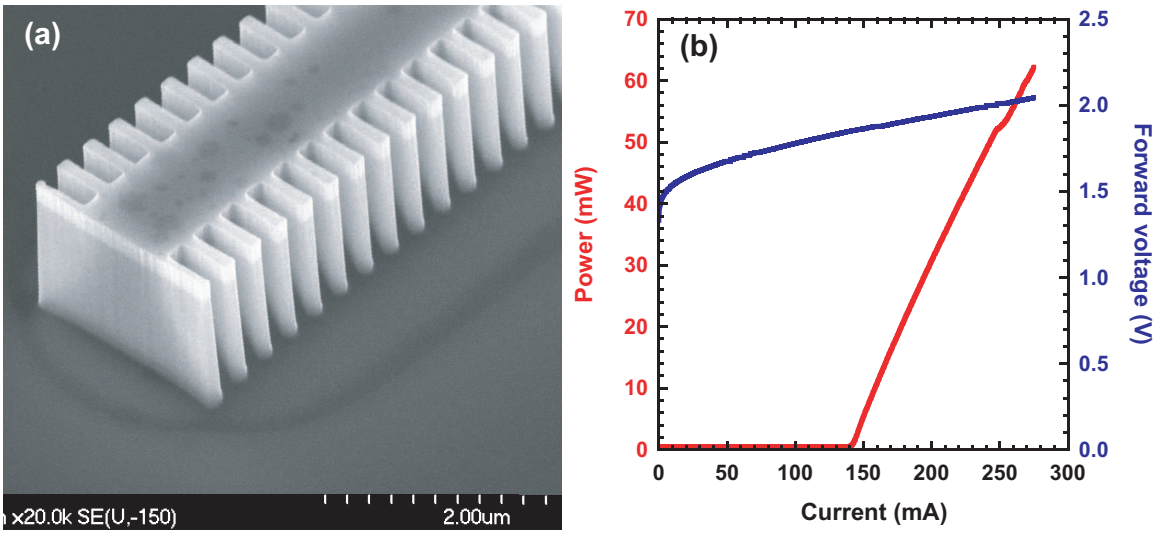

Fig. 1: (a) A scanning electron microscope image of the DFB grating after etching. (b) The power, current and voltage (LIV) characteristics of a facet coated 4 mm DFB laser.

3. DFB Characterisation

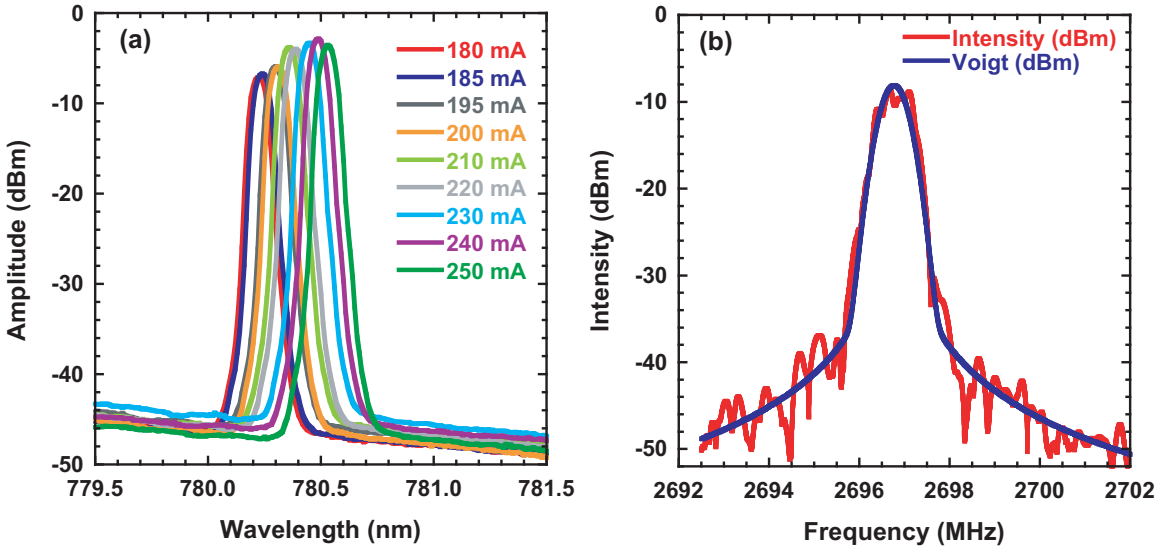

Fig. 2: (a) The spectral performance of a DFB laser emitting around 780 nm. This devices demonstrates continuous tuning with a change of injected current. (b) The linewidth measurement of the DFB laser demonstrating a -3 dB linewidth of 612 kHz over an integration time of 25 μs.

The light-current-voltage (LIV) characteristics of the DFB lasers are demonstrated in Fig. 1 (b) for an anti-reflection (AR)/ high reflection (HR) coated 4 mm long laser. This device has a threshold current of 140 mA and produces over >60 mW. Figure 2 (a) demonstrates the spectra at the target wavelength and shows that the peak wavelength can be tuned by changing the current. A tuning range of approximately 0.3 nm is seen here, however similar devices have demonstrated up to 0.6 nm of tuning through thermal effects from the injected current. This was verified by directly adjusting the temperature of the laser to produce a similar tuning effect. This single-mode tuning around 780.24 nm with no mode hopping is crucial for cold atom applications. The DFB lasers also exhibit a high SMSR exceeding 40 dB. The linewidth of these devices was measured through the heterodyne detection technique [3], which consists of beating the light from the DFB laser with a narrow linewidth reference laser, a commercial 50 kHz linewidth Ti:Sapp solid state laser. The light from the two sources was coupled onto a fast photodetector (Newport 818-BB-45F) and the beat note was measured using a RF spectrum analyzer. The -3 dB point of this peak determines the combined linewidth of the two lasers, however given we know that the commercial laser has a traceable linewidth of less than 50 kHz, we can assume the linewidth observed is dominated by the DFB laser. By fitting this peak to both a Lorentzian and a Gaussian lineshape, we can ultimately get a Voigt fit to determine whether the shape of the peak is correct. In Fig. 2, an almost perfect fit is achieved demonstrating a linewidth of 612 kHz over a sweep time of 25 μs.

In summary, 60 mW DFB lasers emitting at 780.24 nm with narrow linewidths of 612 kHz, side-mode suppression ratios > 40 dB and >0.6 nm of wavelength tuning have been demonstrated for ^{87}Rb cold atom cooling applications.

References

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