Self-pulsation at 480 GHz from a two-color discrete mode laser diode

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Abstract: A discrete mode Fabry-Pérot laser is designed and fabricated to achieve two-color lasing. We demonstrate beating between the two laser modes and self-pulsation at 480 GHz.

OCIS codes: (140.2020) Diode Lasers; (140.4050) Mode-locked lasers.

1. Introduction

Optical clocks are key to future all-optical networks, particularly for 3R regeneration (re-amplification, re-timing, re-shaping). An attractive scheme for optical clock generation is laser self-pulsation by means of beating between two longitudinal modes. This necessitates strong lasing from two longitudinal modes. A common approach to achieve two-color lasing is by use of a multi-element distributed feedback laser, which requires separate gain and phase sections.

We demonstrate here a novel method to achieve a two-color laser by introducing a non-periodic distribution of slots along a ridge waveguide to give a spatially varying effective index, which can then preferentially select specified modes. The slots can be added during the standard processing of a ridge laser, dramatically reducing the complexity of device manufacture. This technique has been previously applied to achieve single mode lasing. We describe here the design and experimental demonstration of a two-color laser using such an index-patterning approach. The two-color laser shows self-pulsation at 480 GHz, the frequency difference of the two selected modes.

2. Design of two-color laser.

It is well established that one can modify the mode pattern of a Fabry-Pérot laser by introducing a small density of perturbations such as slots along the laser cavity, which modify locally the cavity effective refractive index [1]. Until recently, the slot distribution had been determined empirically or by use of a genetic algorithm; thereby limiting the applicability and flexibility of this technique. We recently introduced a semi-analytical method, through which it is possible to solve the inverse problem, and so to specify a slot index pattern to achieve a desired output spectrum, as described in detail in [2]. We used a first-order approximation in a transmission matrix approach to describe the coupling of each slot to the cavity mirrors, while neglecting the scattering between slots. Because we treat each slot as independent of the others, we can then describe their combined effect as a linear sum of terms, where each term has a weighted value determined by the cavity mirror reflectivities and the position of the slot along the laser cavity. The approach to designing a two-color laser that we follow here is a straightforward extension of the approach in [2]. We first choose a desired mode loss spectrum, similar to that in Figure 1(b). We then use an appropriately weighted inverse Fourier transform to calculate the slot density function for the given pattern (Figure 1(a)). We next approximate the continuous density function by a finite set of features (top panel in Figure 1), with the position of each feature finally chosen to ensure that it has the correct phase with respect to the cavity mirrors. We saw in [2] that to select a single mode, m_0, the threshold gain of this mode must be reduced whilst the other modes with mode index m should remain unchanged. A function which has these properties is sinc($m-m_0$). A periodic distribution of sinc-functions, in terms of threshold gain will select a comb of the available lasing modes. This periodic distribution is weighted here by the use of a pair of Gaussian functions to select two modes, as in Figure 1b.

Figure 1a shows the slot density function for a two-color laser and the upper plot shows the position of the slots that best sample this slot density function. The two modes at which lasing is desired are at 1298.9 nm and 1301.9 nm (Figure 1b) and are spaced by four longitudinal modes. The center mode at 1300.4 nm is designed to experience a smaller change of threshold gain than the two desired modes, so that lasing is not expected on this center mode.

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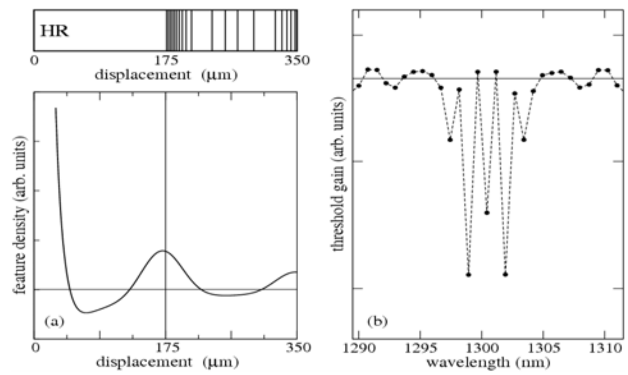

Figure 1. The upper plot shows a schematic diagram indicating the location of the slots along the cavity. (a) The slot density function which is sampled to give the location of the slots. (b) shows the calculated variation of the threshold gain of the longitundinal modes, while the horizontal line represents the round trip mirror losses in the absence of any slots.

3. Experimental results.

We used a 1.3 μm AlGaInAs multi-quantum well structure to demonstrate two-color emission, with a ridge width of 3 μm and cavity length of 350 μm. The device was characterized in continuous wave operation at 25 ^{0}C , where the threshold current was found to be 15.5 mA. At threshold, lasing occurs on mode L1 in Figure 2, but an increase of current allows the intensity in the two modes, L1 and L2, to be tuned such that their intensities are equal. Figure 2 shows the intensity spectrum at 46 mA, where the power in the two modes is equal, and with the two lasing modes separated as designed by 4 cavity modes. There is a small difference in the wavelengths of the lasing modes from that which was designed; this can be explained by small differences in the cavity optical path length of the device from that used in the calculation. Figure 2 also clearly shows two sidebands, SB1 and SB2, which are caused by four wave mixing in the device cavity.

The ultra-fast time trace of the laser intensity was measured using a Femtochrome Research FR-103XL autocorrelator with the drive current set to achieve two-color lasing. Figure 3 shows the autocorrelator output signal, demonstrating a sinusoidal modulation with a frequency of 480 GHz, which corresponds to the frequency difference of the two longitudinal modes. Self-pulsation only occurs at currents where there is two-color operation of the laser.

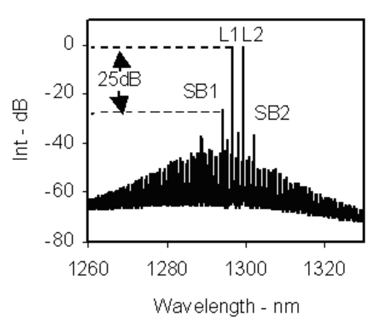

Figure 2 shows the lasing spectrum at 46 mA and 25^{0}C. Two clear laser modes L1 and L2 are shown. Four wave mixing sidebands SB1 and SB2 are also indicated.

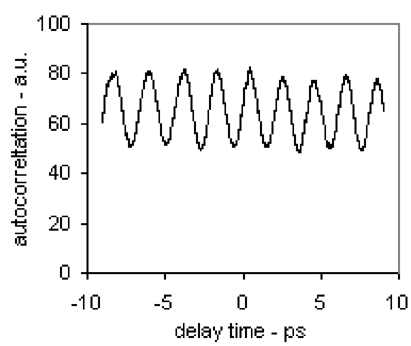

Figure 3: The autocorrelation signal clearly shows a beating signal for a drive current of 46mA at 25^{0}C. The self-pulsation occurs at 480GHz.

4. Summary

We have achieved 480 GHz self-pulsation in a Fabry-Pérot two-color laser, due to beating between two longitudinal modes which have been selected by introducing a low density of perturbations into the laser cavity. The approach demonstrated has considerable advantages, due to the simplicity of device fabrication and that at room temperature only the drive current must be set to achieve self-pulsation.

References.

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