A semiconductor-glass waveguide hybrid laser with ultra-long cavity length

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In order to build external cavity diode lasers with narrow linewidth, a long cavity length L is favoured. However extending L results in increasingly dense longitudinal modes spacing, rendering realizing single-mode oscillation challenging. In this paper a novel laser wavelength selection scheme based on a waveguide circuit which incorporates 3 microring resonators (MRRs) is proposed. Two rings are used for coarse frequency selection while the 3rd MRR with high-Q enables the laser operating at a single longitudinal mode. Such a hybrid laser with ~10 cm cavity length is numerically investigated and high spectral purity single mode oscillation is predicted.

Introduction

Narrow linewidth, tunable diode lasers are of importance for applications such as optical clocks [1] and high bandwidth communication based on advanced modulation formats [2]. Besides monolithic diode lasers, hybrid lasers have come into interest because they promise a lower spectral linewidth. Examples are hybrid lasers based on evanescently gain coupling to high-Q resonators [3], adiabatic gain coupling [4] and butt-coupling to an external waveguide circuit. The latter avoids problems with fabrication, such as due to requirements for lattice matched growth, thereby enabling a free choice of the involved waveguide platforms. Recently we have reported a semiconductor-glass waveguide (Si_3N_4/SiO_2) hybrid laser working at 1.55 µm [5][6]. These glass feedback waveguides can offer extremely low propagation loss (0.1 dB/m [7]), which yielded a narrow laser linewidth of 24 kHz. Further narrowing the linewidth should be possible via increasing the cavity length, L [8]. However extending L increases the longitudinal mode density which requires highly selective intra-cavity filtering for maintaining single-mode oscillation. Here we present an approach based on three microring resonators, two of which are used for coarse frequency selection while the third MRR enables single-mode oscillation.

Short cavity length: feedback with two MRRs

To demonstrate laser mode selection, we have begun with a cavity length that is still relatively short (3.5 mm) where modes are easier to separate. As is shown in Fig. 1(a), the hybrid laser incorporates two MRRs as a waveguide feedback mirror, of which the design parameters are given in [5][6]. The measured reflected power spectrum (normalized to its maximum) of the double MRR mirror is presented in Fig. 1.(b) as the red curve and the blue curve is the normalized power spectrum of the superluminescent diode (SLD) used for these measurements. A total FSR of 46.4 nm enables a wide tuning. Single-mode oscillation (Fig. 1. (c)) with a high side mode suppression (SMSR) ratio of more than 50 dB is obtained. The measured narrowest laser linewidth is 24 kHz.

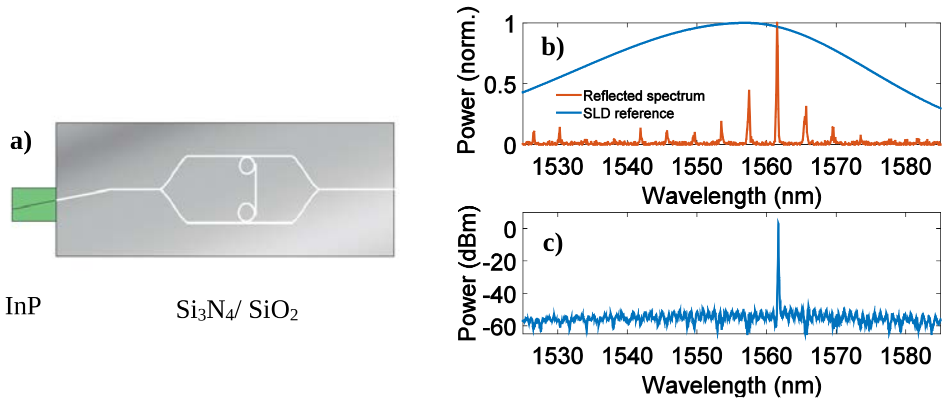

Fig.1 a) Schematic of the hybrid laser with two MRRs; b) the superimposed spectra of the measured reflected power of the double MRR mirror (red) as a function of wavelength and the spectrum of the used superluminescent (SLD) diode (blue), both normalized to their maxima; c) laser spectrum with 50 dB SMSR. The measured spectral bandwidth of the oscillating laser mode is 24 kHz (FWHM).

Long cavity length: feedback with 3 MRRs

In order to further narrow the linewidth of such a hybrid laser, increasing the cavity length is expected to work with proper longitudinal mode filtering. Our scheme (see Fig 3.(a)) comprises a feedback circuit with three MRRs, which extends the total optical length of the hybrid laser cavity to a value of 17 cm. The two MRRs with smaller radii (99 µm, 103.5µm) are used as a coarse Vernier filters and the power coupling coefficients are chosen as 0.2 and those of the 3rd MRR as 0.1. Regarding the 3rd MRR, the FSR should be larger than the FWHM of the double MRR which is fulfilled with a radius of 990 µm. Using these parameters and also the parameters for the InP diode as specified by the manufacturer, we calculated the output properties of the hybrid laser. The used model involves resolving spatially dependent rate equations for the electric field and carrier density [9]. As can be seen from Fig. 2. (b) and Fig. 2. (c), which shows the calculated power spectrum of the three-ring laser, the laser output consists of a single frequency with high side mode suppression (50 dB).

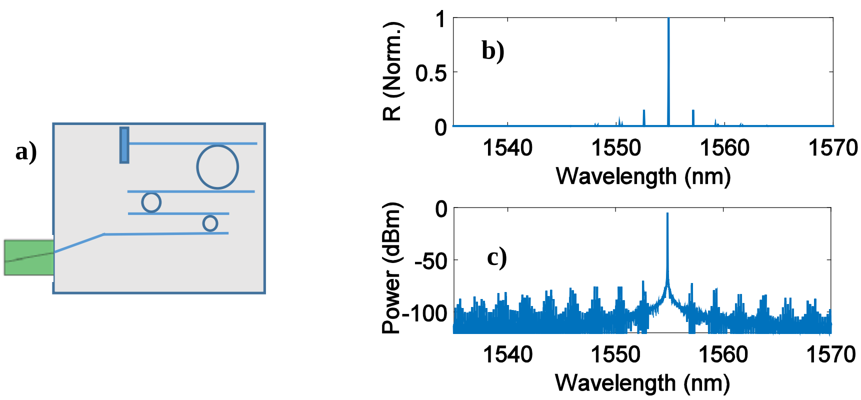

Fig.2 a) Schematic of the hybrid laser with three MRRs; b) the calculated reflectivity as a function of wavelength of the three MRR mirror c) calculated output spectrum shows a SMSR about 50 dB

Laser linewidths

The main point of interest to be achieved with the extended cavity length is a narrow spectral linewidth. To evaluate the validity of our model for linewidth predictions, we have compared the measured linewidths of the short (two MRR) laser with the calculated power spectral density of the frequency noise spectrum [10] and good agreement is found (Fig. 3). It can be seen that the theoretical linewidth coarsely decreases inversely with the output power (see dashed line for the 2 MRR short laser cavity). In the case of the long laser with 3 MRRs, the calculated linewidth decreases with power as well (solid line), however the absolute values of linewidths are much lower. A spectral linewidth as low as 2 kHz should be possible at pump currents compared to those of the short hybrid laser.

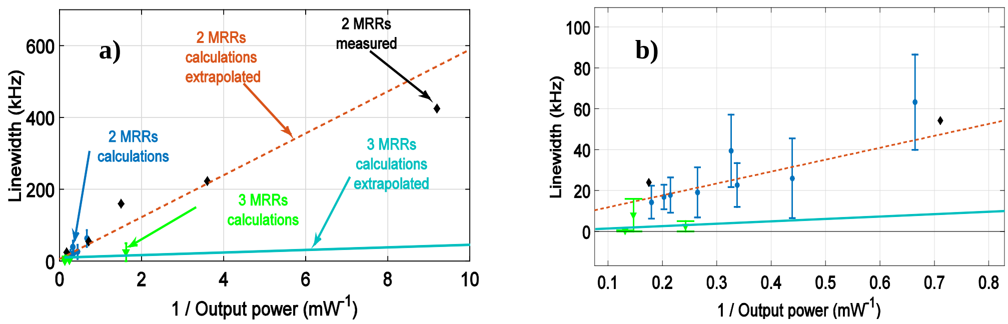

Fig.3 a) Measured linewidth of the laser with 2 MRRs and calculated linewidth for both lasers with 2 MRRs and 3 MRRs; b) zoom in of a)

Conclusions

In summary, we have theoretically investigated the spectral linewidth of a hybrid semiconductor-glass waveguide laser with 17 cm optical cavity length. Based on the advanced, spatially resolved rate equation model for the intracavity electric field and inversion density, which shows reasonable agreement with experimental data from a short-cavity hybrid laser, we conclude that a narrow linewidth in the order of 2 kHz can be realized in single-mode oscillation via intra-cavity filtering using three sequential MRRs in double-pass. Further narrowing the linewidth might be achieved by further increasing both the cavity length and the frequency selectivity of intra-cavity filtering based on Si_3N_4/SiO_2 glass waveguides as these can provide ultra-low propagation loss [7].

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