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Novel Integrated Tunable Laser using Filtered Feedback for simple and very fast tuning

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Abstract *We present a novel integrated tunable laser based on filtered feedback, which combines a simple tuning method with ns switching speed.*

Introduction

Tunable lasers are widely used in telecommunication networks nowadays because they allow flexible reconfiguration of the network and reduce inventory cost for network operators [1].

Most widely tunable lasers employ two Distributed Bragg Reflector (DBR) tuning sections with a comb-like filter response, where the Vernier effect is used to realize a large tuning range with a relatively small tuning range for each of the filters. In this scheme, two control currents are needed for the two DBR mirrors, a third one for controlling the phase, and also the current through the amplifier section needs to be accurately controlled. A tuning table is needed for finding the proper control currents to hit a specified wavelength. Such lasers are available with high power (> 10 dBm), a wide tuning range (> 40 nm) and tuning speeds in the ms-range [2]. So far, attempts to simplify the control scheme have not yet led to competitive devices.

We have invented a novel discrete tuning mechanism based on filtered feedback, which combines simple wavelength control with very high switching speed [3]. The principle of this Integrated Filtered Feedback Tunable Laser (IFF-TL) has first been demonstrated by Matsuo et al [4], where two coupled micro-ring filters were used for controlling the wavelength. It was shown that with this approach the frequency drift can be reduced below 1 GHz. In this paper we present a laser which uses a compact AWG integrated with short SOA gate switches for controlling the wavelength. In an earlier paper [5] we have shown that these short gate switches allow for switching times of a few ns. In this paper we demonstrate that the filtered feedback principle in combination with an AWG and a SOA gate switch array allows for simple and stable tuning. The fast tuning time makes the device suitable for packet switching applications.

Device details, design and fabrication

A schematic picture of the novel IFF-TL is shown in fig 1. A Fabry-Perot (FP) laser is connected to an AWG filter that routes the laser light to an array of SOA gate switches. The FP laser is formed by an SOA and two deeply etched Distributed Bragg Reflector (DBR) mirrors. The laser cavity length (L_{cav} = 822 µm) is chosen such that the mode spacing (given by $\Delta\lambda = \lambda^2 / 2N_g L_{cav}$) equals 50 GHz (0.4 nm) - the channel spacing in the standard ITU-grid used for telecom applications. N_g is the group index of the waveguide (3.65) and λ is the central wavelength (1.55 µm).

The FP laser is coupled to an AWG filter with a 3.2 nm or 400 GHz channel spacing. The channel spacing of the AWG can be any multiple of the mode spacing of the FP laser. In this realization a 400-GHz spacing was chosen in order to keep the AWG small.
The AWG splits the light of the FP laser in 4 waveguide branches. The difference in FP modespacing and AWG channel spacing allows us to be sure that at least one FP mode falls within the passband of each AWG channel. Each branch contains a 100-µm-long SOA that works as an optical gate. When the SOA is not biased it will absorb the light, but when it is forward biased (5-15 mA) the light will be transmitted. The light is then reflected at the end of each waveguide, either by another DBR mirror, or a cleaved chip facet. The feedback light forces the laser to switch to the wavelength selected by the SOA gate array. The output light leaves the chip through the opposite DBR mirror.

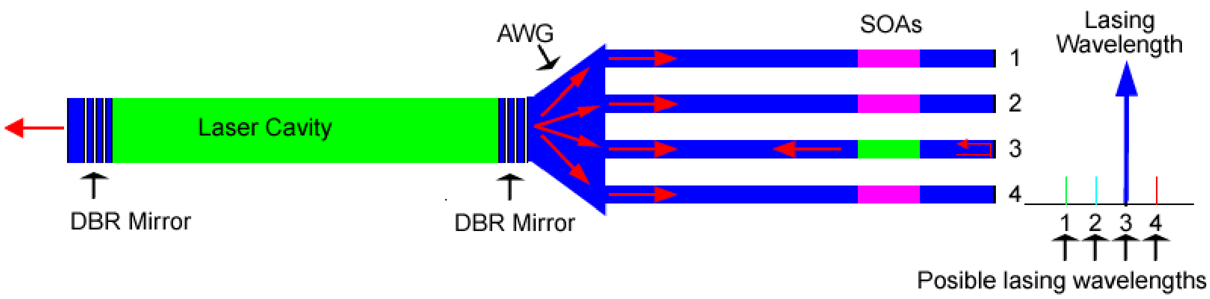

Fig. 1: Schematic diagram of the new Integrated Filtered-Feedback Tunable Laser

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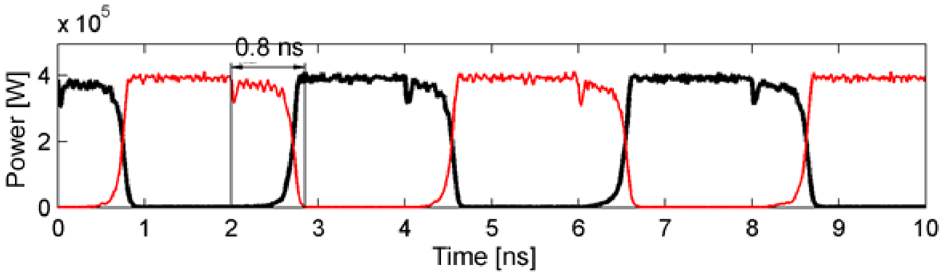

Fig 2: Simulated switching speed. Deterministic model predicts switching within <1.5ns.

One of the key components of this novel device are the DBR mirrors, which have been deeply etched as shown in [6]. They provide high reflectivity over a broad wavelength range and can be placed anywhere on the chip. This allows very accurate control over the FP laser length and thus the modespacing. The gaps that form the DBRs are etched completely through the waveguide layer in order to obtain maximum reflectivity. These gaps are filled with BCB (refractive index ~ 1.54). We use a 3rd order DBR design of 2 periods, where the length of each section equals $¾\lambda/N$ (N is the effective index of the mode in each material, λ is the wavelength corresponding to the maximum material gain, 1.55 µm). This results in BCB filled gaps of 750 nm and 360-nm-long semiconductor sections.

Device Modeling

The operation-principle was tested by numerically simulating a multimode laser. The presence of feedback in one mode was modeled using a Lang-Kobayashi system of rate equations extended with a delayed term which accounts for the frequency selective optical feedback [7]. The model also adds spontaneous emission noise, since this plays an important role in the switching dynamics. An example of the result of such simulations is shown in fig 2. In that figure, the black and red lines represent the output power of the device switching between two gates. When the gate 1 is biased in order to provide feedback, the corresponding mode will stably lase. If the feedback is moved to another channel, for example by forward biasing the SOA in gate 2 the operation of the system settles to the second mode. The model predicts that the switching-time between the two modes is 0.8 ns. This result matches with measured switching speeds in similar devices [4,5].

Characterization

We measured a threshold current of 40 mA at 15 ^{0}C. For the characterization of the tunability, the device has been forward biased at 45 mA. The performance of the device as a tunable laser is shown in fig. 3. The colors represent the optical spectra of the device when the various gates are operated in forward bias. The separation between the 4 possible lasing wavelengths is equal to 3.2 nm, or 400 GHz corresponding to the channel spacing of the AWG. The sub-threshold peaks show the mode-spacing of the FP laser, which are positioned 50.5 GHz apart; only 1% mismatch with the designed 50 GHz.

In fig. 3, it can also be observed that the sub-threshold peaks are coinciding for all 4 lasing spectra. This is a good indication that the carrier density in the main laser cavity is the same, and the temperature does not vary much at all. This also confirms that the wavelength is tuned due to small feedback received from the gates, and the device does not operate as an extended cavity laser.

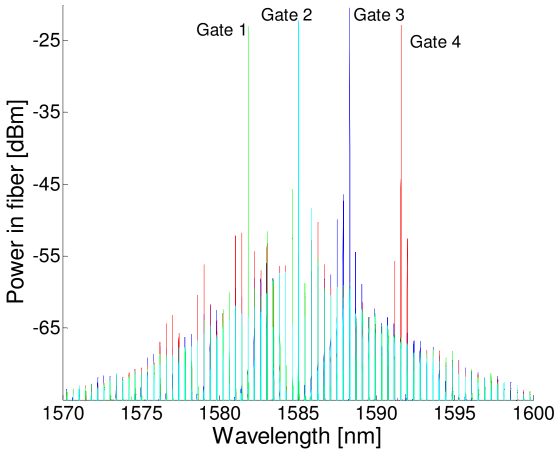

Fig. 3: Optical lasing spectra of the IFF-TL.

Conclusions

A novel concept in the field of tunable lasers has been demonstrated. The AWG-based IFF-TL is easy to control and has nanosecond wavelength switching speed. The device presented in this paper has 4 wavelength channels, but the concept can easily be extended to a larger number of wavelengths. The fast switching speeds makes the device suitable for packet switching; the simple control scheme is advantageous for applications in access networks.

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