Design of Quasi-Continuously Tunable Laser Based on Filtered Feedback for Sensing Applications using Generic Building Blocks

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Abstract *We present the design of a novel quasi-continuously tunable laser based on the filtered-feedback principle. This laser was specifically designed for use in Fiber Bragg Grating optical sensing applications. It can sweep rapidly over 10 discrete wavelength bands in the 1520-1580 nm wavelength range. The aim is to provide simultaneous wavelength scanning rates of up to 1 MHz. The laser was designed using generic building blocks and is therefore compatible with the future generic foundry infrastructure that is being set-up in Europe.*

Introduction

Using Fiber Bragg Gratings (FBG) for sensing applications has many advantages over equivalent electronic measurement techniques. FBG sensors can be used to measure stress and temperature changes in large structures, while being immune to electromagnetic interference. The measurement can be conducted over large distances and the glass fiber can be applied in harsh environments where conventional electronic systems cannot be used. The application areas for using this type of optical sensors are therefore very broad ranging from oil & gas industry to aerospace and medical applications.

FBG readout units

The key component in a FBG based sensor system is the readout unit. The readout unit provides the light signal going into the fiber and measures the reflected spectrum, translating it into the actual measurement data. The readout unit determines to a large extent the performance and cost of the system. It is also the largest component in the system in terms of physical size. For some applications, such as aerospace, size and weight of the readout unit are very important.
Recently experiments have been conducted using monolithically integrated tunable lasers [1] as an alternative to a more commonly used broadband light source or fiber laser source. The tunable laser approach is shown schematically in figure 1. The main advantage is that the light energy can be flexibly concentrated in a narrow wavelength band and therefore used efficiently. The accuracy and speed of the system is determined by the wavelength accuracy, linewidth and tuning speed of the laser.
Although telecom-grade tunable lasers in principle can be tuned quasi-continuously over a wide wavelength range, the optical elements and electronics are optimized to make the laser operate on a 50 GHz (0.4 nm) telecommunication grid. The laser can therefore only be tuned quickly over a 0.4 nm wavelength band. Covering a wider wavelength band requires switching between different laser modes which cannot always be done

stably without exciting other cavity modes and inducing wavelength drifts due to temperature changes caused by the tuning currents [2].

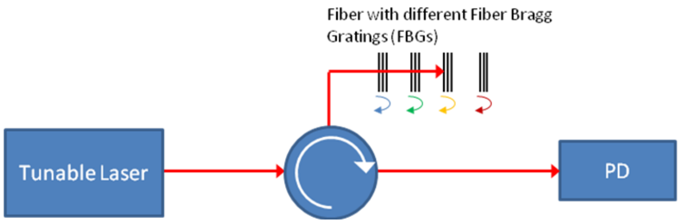

Figure 1: FBG readout using a tunable laser as light source

Filtered feedback tunable laser for FBG sensing applications

Recently we presented a novel type of tunable laser that can switch between discrete laser modes very rapidly (1-5 ns) [3]. The laser consists of a Fabry-Perot (FP) laser with a fixed cavity length, creating a set of 50 GHz spaced laser modes. The FP laser is coupled to an Arrayed Waveguide Grating (AWG) filter that selects certain mode groups out of the FP modes and route them to different short Semiconductor Optical Amplifier (SOA) gates. If one of the SOAs is opened by applying a small forward bias, the light of the corresponding modes is transmitted and reflected by a broadband mirror back into the laser cavity, locking the FP laser to one of the reflected wavelengths (see figure 2&3). The output of the laser comes from the other side of the FP laser.

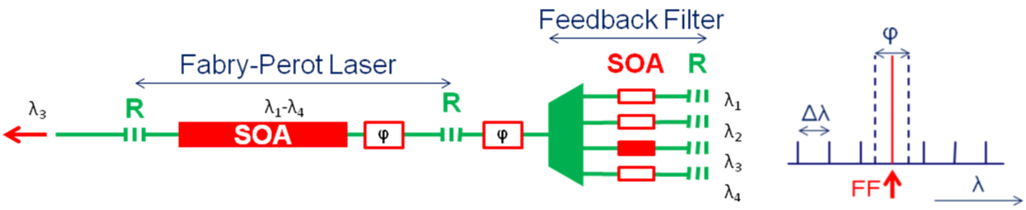

Figure 2: Schematic concept of filtered feedback laser (left) and schematic picture of laser spectrum (right). The mode spacing Δλ is determined by the FP laser cavity length. The lasing mode is selected by opening one of the gates in the feedback filter (FF). The phase section (φ) inside the FP laser cavity can be used to finetune the lasing wavelengths, while the phase section in the feedback filter determines which sub-mode within one AWG channel will have the strongest feedback.

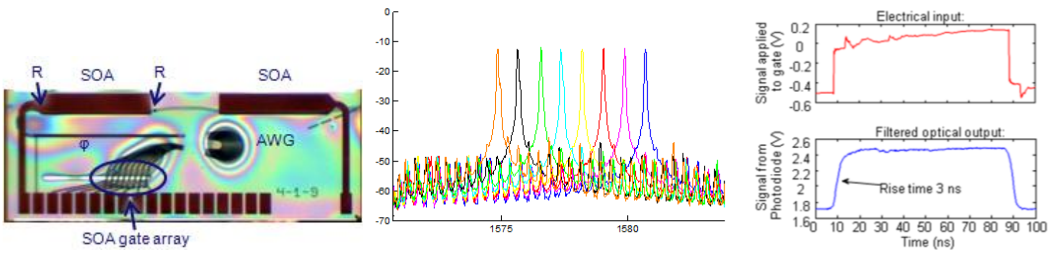

Figure 3: Picture of previously realized tunable laser (left) (chip size: 1.0 x 2.5 mm, no intra-cavity phase shifter present in this device), detail of laser spectrum (middle) and measured switching behavior (right)

The AWG filter does not have to be matched to 50 GHz mode spacing of the FP laser. For example, a 200 GHz AWG would pass 4 laser modes to each SOA gate in the feedback section. By adjusting the phase of the feedback signal, we can select which mode within one AWG channel will have the best phase matching and therefore will switch the laser. This was already suggested by the measurements in [2] and is now confirmed by calculations on the laser threshold gain (fig. 4) for 50 Ghz Fabry-Perot

laser (cavity length L_{FP}=822 µm) coupled to a 2671.5 µm long feedback cavity (3.25 times the length of the laser cavity). The feedback cavity contains a 200 GHz-wide (FWHM) band pass filter simulating the transmission characteristics of an AWG channel. In the plot, the stars indicate the intersection between the vertical dashed lines that represent the FP-modes with the resonances of the feedback filter. The mode with the lowest threshold gain will start lasing first.
By choosing the feedback cavity length $L_{FB}=(x \pm y)*L_{FP}$ where x is an integer and y is a fraction given by the FP-mode spacing divided by the AWG channel spacing (in this case $x=3$ and $y=50/200=0.25$) there is only 1 wavelength for which the FP laser and the feedback cavity are both in resonance. By changing the bias on the feedback phase section, the feedback resonances shift and a different FP mode can be selected.

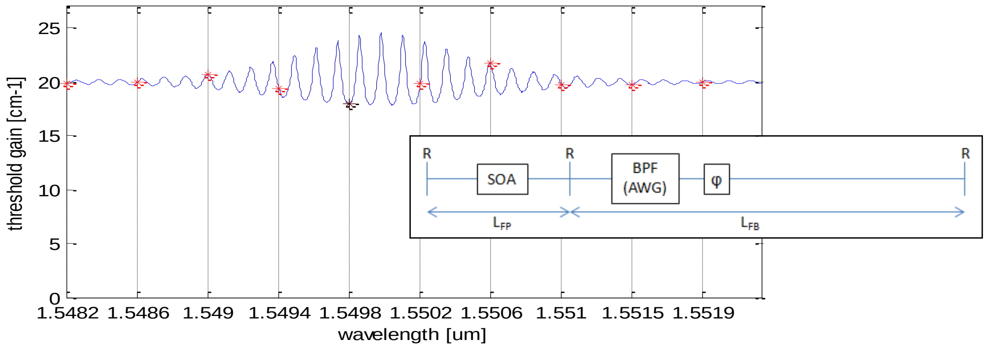

Figure 4: Calculated threshold gain for L_{FP}=822 µm (50 GHz mode spacing) and L_{FB}=2671.5 µm and a 200 GHz AWG Band Pass Filter (BPF). The vertical dashed lines indicate the FP laser mode positions. The stars show the intersections between the laser modes and the feedback resonances. The star with the lowest threshold gain shows which mode will start lasing.

The laser modes can be fine- tuned by an in-cavity phase section. We can use this phase section to align the FP modes with an FBG sensor peak, but also to then quickly sweep over that peak. We expect that this continuous sweeping can be done up to 1 MHz frequencies with accurate repeatability. The fast switching of the tunable laser then allows us to quickly readout several FBG sensors simultaneously.

Chip design

Figure 5 shows a picture of the mask layout of the proposed tunable laser device. The device was designed in the generic integration technology platform provided by the EuroPIC consortium [5]. The SOAs, phase shifter elements and the spot size converter (SSC) are shown as 'black boxes', which are later filled in by the foundry that is responsible for the fabrication of the chip. In this way the designer does not have to know the details of the fabrication, but only the black box performance such as gain spectra in case of an SOA or refractive index change as a function of bias current is case of a phase shifter.
The current design uses Multi-mode Interference Reflectors (MIRs) [6] to form the on-chip broadband mirrors: two 50% MIRs form the FP laser cavity and ten 100% MIRs terminate the feedback arms. The 50% MIRs reflect 50% of the incoming light back into the FP laser cavity, while 50% is guided either to the feedback section (right MIR) or to the output of the chip (left MIR). The light leaves the chip through a spot-size converter (SSC) that enhances the coupling of the light out of the chip. The FP laser is connected to the AWG through the feedback phase shifter and an extra SOA that can be used to

compensate the AWG losses. Each feedback arm consists of a 50 µm long SOA gate and a 100% MIR.

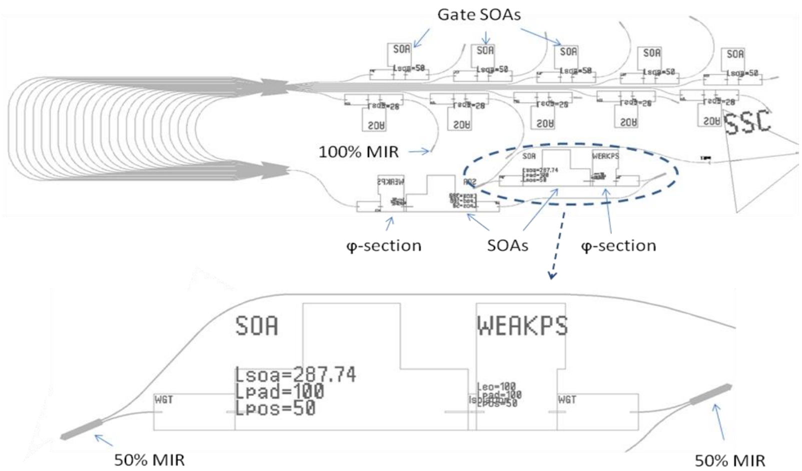

Figure 5: Mask layout of tunable laser chip (top) with detail of FP-laser part (bottom). The chip is constructed using Basic Building Blocks such as SOAs, phase shifters (WEAKPS), spot size converter (SSC) and waveguide transition elements (WGT). The circuit size is roughly 1 x 4 mm.

The AWG has a 100 GHz channel spacing and 10 feedback arms and can therefore cover an 8 nm wavelength range. On the same 2 x 6 mm design cell there are two other laser designs using 400 GHz AWGs with also 10 channels, covering a 32 nm spectral range. In both designs the feedback arm lengths are chosen in such a way that there is only 1 FP mode coinciding with a feedback resonance within one AWG channel as described in the previous paragraph.

Conclusion

In this paper we described the design of a new tunable laser for fiber sensing applications. The different components of the circuit allow for much flexibility in the laser design, so it can be tailored to specific sensor applications. The generic integration model allows these different designs to be manufactured together in a single multi-project wafer fabrication run, so costs can be low, even for low volume markets.

References

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The research leading to these results has received funding from the European Community’s Seventh Framework Programme FP7/2007-2013 under grant agreement NMP 228839 EuroPIC