

Towards a Widely Tunable Laser on Silicon with Liquid Crystal Technology

W. De Cort^{1,2}, R. Baets¹, and K. Neyts²

¹ UGent, Department of Information Technology, Photonics Research Group

² UGent, Department of Electronics and Information Systems, Liquid Crystals and Photonics Group

We show the first steps towards the realisation of a widely tunable laser integrated on a silicon chip. The laser cavity will be fabricated in the Silicon-On-Insulator material system and we want to achieve amplification of the light by applying semiconductor nanoparticles. We will discuss the first experiments concerning these nano-particles. Wavelength tuning will be achieved by exploiting the electrooptic properties of liquid crystals as a top layer on the laser structure. We will demonstrate early realisations of wavelength tunable devices.

Introduction

In optics, tunable lasers have become highly important devices. They act as transmitters in telecom networks or as light sources in sensing or spectroscopy applications. However, the ideal tunable laser has not yet been realised. This laser would combine a compact and cheap design with a wide tuning range, simple control and sufficiently high output power. Existing tunable lasers involve external cavity tuning, complicated gratings with difficult control, limited thermal or carrier-induced tuning and thus fail in at least one of those areas. In this article we propose a route towards a laser that addresses all the issues at once.

Concepts and materials involved in our laser

In this section we describe the concepts involved in the design and fabrication of the laser. We start with a short introduction on laser basics after which we introduce the different physical building blocks of our design.

Laser basics

A laser in its simplest form consists of a *gain area* and *mirrors*. Together they form the *laser cavity*. The material in the gain area is pumped to achieve sufficient amplification of light. The pump source can be an electric current or can be another light source. The mirrors reflect the light back and forth through the cavity. Which wavelength becomes dominant and eventually begins to lase, depends on the length of the cavity, the reflective properties of the mirrors and the properties of the gain material.

Building blocks

Silicon-On-Insulator (SOI) is seen today as the most important and promising material system in the world of photonics. The primary reason, next to the fact that silicon is transparent in the near infrared, is that components in SOI can be fabricated in mass production with the techniques used in the since long established CMOS technology. This makes the cost of fabrication extremely low. We will use this material system to define the physical structure of the laser. Examples of structures in SOI can be seen in figure 1.

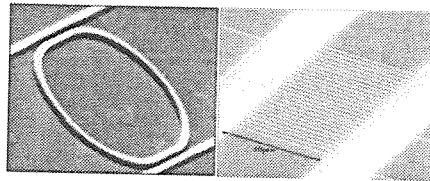


Figure 1: Structures in SOI. Left: a ring resonator, right: a grating. [1]

Colloidal nanocrystals (NC) are extremely small semiconductor particles which are synthesized in a liquid. When optically excited, these particles efficiently emit light at a wavelength which depends on their size. As the size can be controlled through the fabrication process, control over the emission wavelength is possible. The nanocrystals also have a capping layer of organic material which prevents them from clustering and which gives them their excellent luminescent qualities. [2]

Nematic liquid crystal (LC) is a liquid of which the individual molecules exhibit a certain degree of order. The molecules are rod-shaped and are all aligned more or less in the same direction. It is important to note that under influence of an electric field, the molecules align themselves along the fieldlines and thus the refractive index of the material changes.

We will make smart use of the different properties of these materials and their combinations to design and develop our laser.

The route towards a working laser

SOI and LC for tuning

We already mentioned that mirrors form an essential part of a laser. In the SOI material system we implement them in the form of wavelength-selective optical filters (for examples, see figure 1). When light travels in an SOI structure, it sees a refractive index that consists of contributions from both the SOI-system and the material above the SOI. We call this the *effective refractive index*. The wavelengths that get filtered out by an

optical filter depend on this effective refractive index. The idea is that if we can change the refractive index of the material on top of the optical filter, we can change the filtered wavelengths. Only these wavelengths will be reflected back into the laser cavity. Through the use of liquid crystal this wavelength-tuning can be realised in a rather simple way, i.e. with an electric field.

A practical implementation of a tunable filter is a ring resonator (see the left side of figure 1) with a top layer of liquid crystal. We have fabricated ring resonators with liquid crystal on top. A schematic cross-section can be seen in figure 2(a). We were able to tune the wavelength by applying an electric field over the liquid crystal. In figure 3 we show an example of the tuning. The curve features a threshold voltage and a monotonous behaviour.

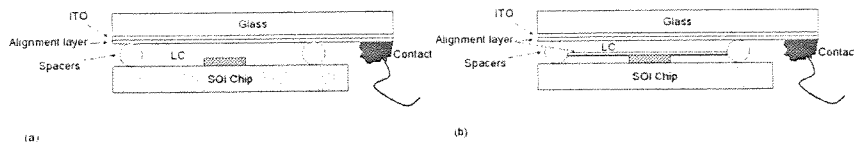


Figure 2: (a): Scheme of a basic liquid crystal cell on a SOI chip, (b): Scheme of a liquid crystal cell on a *planarized* SOI chip.

Although this (modest) tuning can be achieved quite easily, there are still problems with these basic tunable filters, in particular with the alignment of the liquid crystal molecules. The alignment layer on the glass plate gives the liquid crystal molecules a preferential

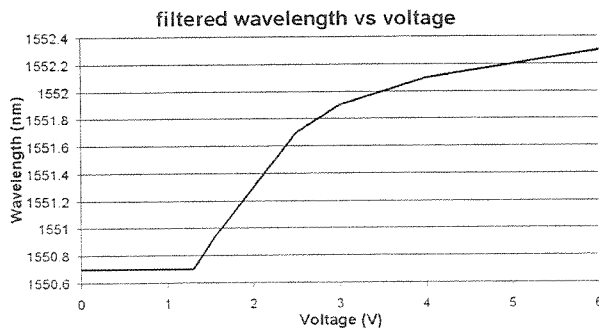


Figure 3: Filtered wavelength in function of the applied voltage in a ring resonator.

direction in the hope that the LC layer would be homogeneous in the entire area above the optical filter. This is however not the case. We have seen that on the surface of the SOI-chip, the alignment of the LC molecules is distorted. Also the structured surface of the chip causes defects and non-uniformities in the LC layer. Because of these effects, the losses increase and reproducibility is lost. To solve this problem, control of the alignment

on the SOI surface is needed. A solution to this problem is the planarisation of the SOI-chips through chemical mechanical polishing (CMP). This process involves deposition of oxide and a polishing step to make the surface of the chip completely flat. On such a flat surface we will add another alignment layer which will give total control over the liquid crystal layer, see figure 2(b).

SOI and NC for gain

Silicon is an ideal material for integrating passive optical functionality. It is transparent in the infrared and the production processes of devices in silicon are very well known. However, silicon has a major drawback. It is incapable of generating optical gain. This is why active devices such as lasers have not yet found an easy implementation in a silicon based material system. As we want to create a laser based on SOI, we have to find a way around this problem.

As nanocrystals have promising properties concerning photoluminescence, we will use them to create the necessary gain through *optical pumping*. When light travels in an SOI waveguide, part of the light also feels the material on top of the SOI (this was also the base of the tuning mechanism discussed earlier). If there is a gain material, in our case the nanocrystals, present over the waveguide, the light will get amplified. In one way or another, the nanocrystals are to be deposited on the SOI. We will do this by making a suspension of the nanocrystals in the same liquid crystal that we use for the tuning of the wavelength.

We will use PbSe nanocrystals with a diameter of around $5nm$ as they emit light at $1550nm$ which is the primary wavelength used in telecom applications.

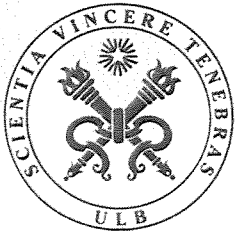
Making a suspensions of nanocrystals in liquid crystal has proved to be a troublesome task. Early experiments showed that nanocrystals, when combined with liquid crystal, tend to cluster and lose their luminescence. This can have several reasons. As nanocrystals are apolar, they are difficult to combine with a polar medium (like water). Liquid crystals often have a polar group which can cause the problems. It is also possible that the liquid crystal breaks the bonds between the particle and its capping layer. A thorough understanding of the interaction of liquid crystal and capping material is needed in order to find compatible materials.

Conclusion

We have proposed a new concept of a laser and discussed the steps we are taking to realise it. We mentioned the difficulties we encounter in our ongoing research and proposed solutions to those problems.

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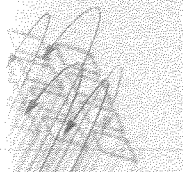
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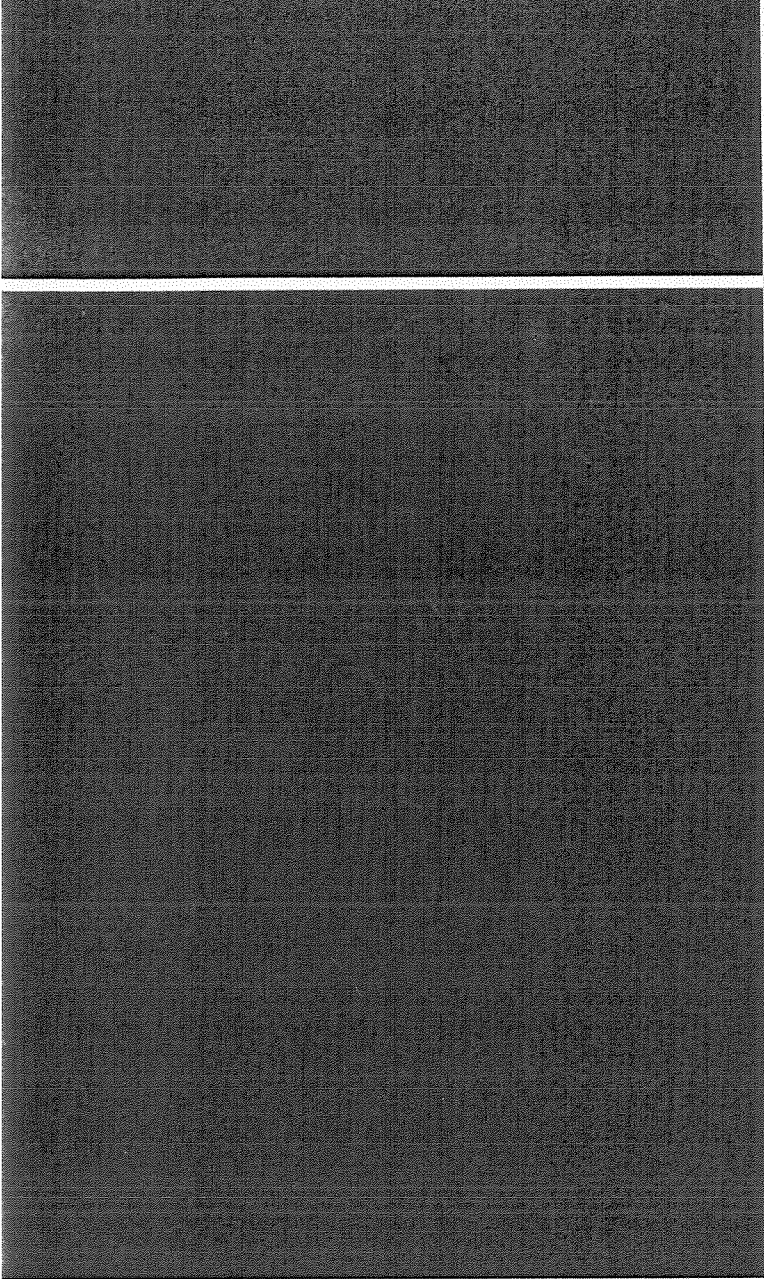
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