Liquid Crystal Orientation on Patterns Etched in Silicon-on-Insulator

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Liquid Crystals have many applications in photonics, but often the geometrical properties of the photonic structures give problems for controlling the alignment of the liquid crystal. We demonstrate the effect on the orientation of a nematic liquid crystal by structures etched in Silicon-on-Insulator (SOI) wafers, produced by photolithography. We characterize the alignment effect of several patterns, including configurations that allow bistable director orientations. Also, the influence of a surface treatment (like deposition of a monolayer on the structured surface) is discussed.

Introduction

Liquid crystals (LCs) have many potential applications in photonics because of their enormous electro-optical properties. In integrated optics, the use of LCs can lead to very compact electrically tunable components. An example is given by silicon-on-insulator (SOI) devices with a liquid crystal cladding [1].

However, one problem often arise when using liquid crystals in integrated components: the small features of these components influence the orientation of the liquid crystal molecules (also called the director of LC); and exactly this orientation determines the optical properties (it gives the optical axis and thus the refractive index tensor). The problem is the worse if an important fraction of the light in the liquid crystal is close to the surfaces or to sharp features, which is often the case. As a consequence, a detailed characterization of the alignment properties is needed before designing the photonic devices.

When determining the influence of a photonic component geometry on the alignment of liquid crystal, not only the geometry but also the details of the fabrication process play an important role. Small variations in a surface, for example due to an etch process, can have a significant influence on the orientation of the liquid crystal director. Moreover, the sharpest features –which have often a large dependency of the fabrication process – have the most important influence on the alignment.

In the work we present here we have investigated in a systematical way the alignment of nematic liquid crystals on patterns etched in silicon-on-insulator. The patterns in the SOI were fabricated by deep-UV photolithography. This technique does not give the finest structures but it has the potential to become the standard for photonic SOI components because it allows mass production.

Liquid Crystal Alignment in Complex Geometries

Nematic liquid crystals consist of long-shaped molecules that tend to align parallel to each other [2]. The resulting structure has some crystal-like properties like optical anisotropy. The unit vector in the alignment direction is called the *director*.

Because the aligning forces are rather weak, molecules are not always perfectly parallel, and on a macroscopic scale the director may vary. The tensions that are created this way give an increase of internal energy of the material. This energy can be calculated as a function of the material parameters and the type and magnitude of the director variation.

When a liquid crystal contacts to another material (in most cases a solid), the liquid crystal molecules that are close to the surface feel inter-molecular forces with the molecules on the other side of the surface, in addition to the aligning force of the surrounding liquid crystal molecules. The LC molecules will reorient themselves in a way dependent on the material parameters and the state of the surface. For example, silicon tends to align the molecules parallel to the surface. This is called *planar anchoring.* If, on the contrary, molecules are preferentially orthogonal to the surface, the anchoring is said to be *homeotropic*. When the alignment differs from the preferential direction, the difference can be associated with a surface energy.

If the liquid crystal is confined between several surfaces, it will try to minimize the total internal energy, i.e. the sum of the surface and bulk energies. For complex geometries, one often finds multiple stable minima. For optical applications this means one can create structures with the same geometry but with different optical properties.

Structures

The structures we examined were etched in the top silicon layer of an SOI wafer, with etching depths of 70 and 220 nm. Before putting on the liquid crystal, a glass plate was placed on top of the SOI sample, and was hold a few micrometers above it by microspheres. The liquid crystal was inserted in the isotropic state (high temperature) by capillary forces between the glass and the silicon surface. The resulting structure is shown in Figure 1.

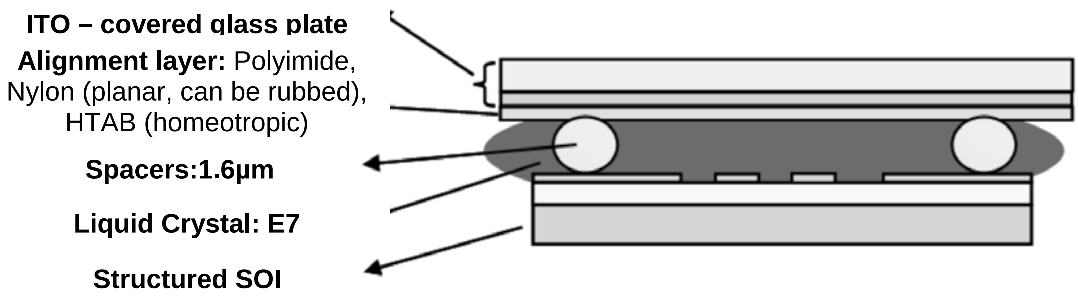

Figure 1: Cell structure

In order to determine accurately the alignment behavior we tested real photonic structures (waveguides, ring resonators, photonic crystals) as well as non-photonic structures. The last group includes all kind of (2dimensional) gratings with pitches ranging from few 100s of nanometers up to 50 µm. While it is well known that a one-dimensional grating gives a homogeneous director orientation parallel to the grating, two-dimensional gratings can give any type of alignment. For example, for small pitches, checkerboard-like patterns give two equivalent alignment states along the diagonals of the pattern [3].

Besides changing the geometrical parameters, we also changed the chemical parameters of the silicon surface by covering it with a surfactant. For example, by dip coating the SOI samples with hexa-decyl-trimethyl-ammonium bromide, we could change the alignment on the silicon surfaces to homeotropic.

Results

In order to see the liquid crystal orientation in the cells, they where placed under microscope “between crossed polarizers”. This means that the sample is illuminated by polarized light, while the reflected light passes through a polarizer orthogonal to the polarization of the incident light. Therefore, only light that has obtained a polarization change (due to the birefringence of the LC) is being measured.

An example of the aligning properties of etched silicon structures for liquid crystals can be found in Figure 2. It shows the resulting view for a simple one-dimensional grating. The alignment layer on top of the liquid crystal was chosen to be a strong planar anchoring with alignment direction orthogonal to the grating. Above the plane silicon (the brightest regions in the figure), the liquid crystal forms a homogeneous layer: the LC molecules are parallel to the upper alignment direction everywhere. Above the grating (the dark stripes), the lower liquid crystal is parallel to the grating while the upper molecules are parallel. In between, there is a twist that can be either left or right-handed, which gives the two types of domains in Figure 2.

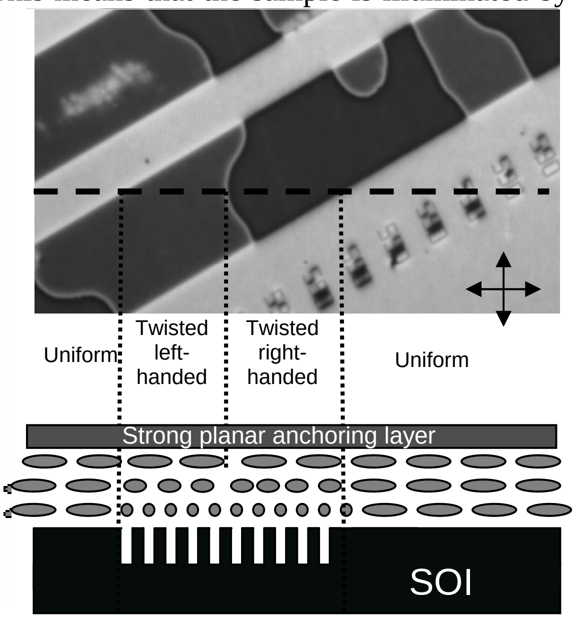

Figure 2: Picture and schematic liquid crystal configuration for a 1D grating.

The same experiment for different grating pitches showed good alignment for pitches between 400nm and 3µm. Larger pitches will give areas of homogeneous alignment (like above the planar silicon), while smaller pitches have too many defects due to the fabrication.

Other observations were that the importance of the influence of the etch depth is limited, and that covering the silicon with the surfactant changes the alignment direction in a way it is orthogonal to the grating direction.

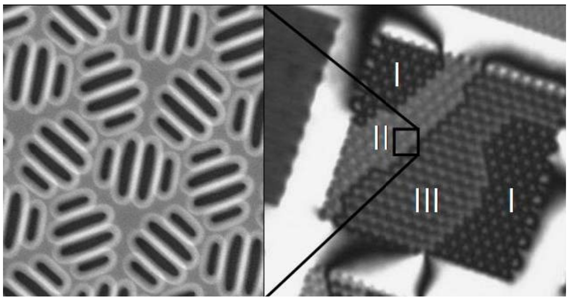

Figure 3: SEM view (left) and view with crossed polarizers (right) of a tri-stable structure in SOI. The size of a unit cell is about 1.6µm

Figure 3 shows an example of a more complex pattern. On the left hand side the microscopic pattern is displayed. It has a three-fold symmetry. On the right side, one can see the structure covered with liquid crystal in crossed polarizer setup. The top layer has no preferential alignment, which gives three equivalent alignment states.

The conditions for obtaining the large domains in the 50µm x 50 µm pixel of Figure 3 are critical: when the cooling process after the filling with liquid crystal is too fast, the domains will be much smaller. And when the cell is too thick, only one big domain will form. Therefore, these structures are very useful for optimizing the fabrication process of SOI components covered with liquid crystal.

Conclusion

We examined the alignment of liquid crystal on patterns etched in silicon-on-insulator, fabricated with deep UV photolithography. We found that a textured silicon surface has a strong influence on the alignment of a liquid crystal layer on top of it, and we were able to define more complex (multi-stable) alignment patterns.

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