

Silicon-on-Insulator (SOI) rib waveguides with Liquid Crystal (LC) overlay

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In a nematic liquid crystal, the orientation of the director can be switched by applying an electric field. In the past, liquid crystals have been combined with glass fibres, photonic crystals and SOI waveguides. The appeal of SOI waveguides is due to the fact that they are fabricated using the same processes as those of complementary metal oxide semiconductor (CMOS) technology. Their most distinctive feature is high index contrast which results in tight optical confinement. SOI waveguides combined with liquid crystal could lead to tunable integrated optical devices.

In this work, we consider an SOI waveguide which is covered by LC such that it forms the upper cladding of the waveguide. We determine the full dielectric optical tensor of the LC upper cladding for a given applied voltage by using a finite element based liquid crystal hydrodynamics solver [1]. Next we use a finite element based fully anisotropic modesolver [2] to compute the modes supported by the whole structure i.e. rib waveguide + LC cladding. We do this for waveguides with widths varying from $1\mu\text{m}$ to $0.24\mu\text{m}$, the height of all waveguides considered is fixed at $0.22\mu\text{m}$. The modes supported by SOI waveguides are either transverse electric (TE) or transverse magnetic (TM). A TE mode is one for which the x-component of the electric field is the most dominant of all three (x, y, z) field components. Whereas a TM mode is one for which the y- component of the electric field is the most dominant of the three field components. Consequently, the refractive index ‘felt’ by TE and TM modes in the cladding depends on the orientation of

the director in the liquid crystal. We start with the director aligned parallel the z-axis; the TE and TM modes see the same index (the ordinary index (n_o) of the liquid crystal) in the cladding.

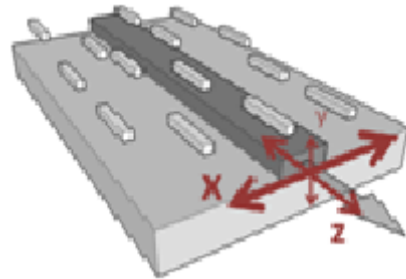


Fig. 1 Rib waveguide with liquid crystal cladding. TE and TM modes see the same index in the cladding.

By applying a voltage between the bottom of the waveguide and the top of the liquid crystal we can switch the director so it now lies at an angle to the x-z plane.

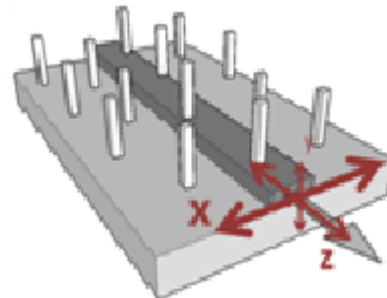


Fig. 2 Rib waveguide with liquid crystal cladding. When a voltage is applied, the director is vertically aligned. The TM mode sees a higher index in the cladding than the TE mode.

In this configuration, the TM mode feels a cladding index which is an average of the extraordinary and ordinary refractive indices of the liquid crystal weighted with the angle between the director and the x-z plane.

On the other hand, the TE mode still feels an index n_0 in the cladding. As such we can increase the effective index of the TM mode while keeping that of the TE mode more or less constant. The refractive index of the TM (TE) mode increases (decreases) by an amount equal to about 20% (3%) of the liquid crystal birefringence. For a given waveguide geometry; as the applied voltage is increased, the cladding index felt by the TM mode increases. The TM mode becomes less and less confined to the waveguide, leaking out into the cladding. For a high enough voltage, the TM mode can be driven into cut-off i.e. it isn't guided anymore. As such we realize an electrically controllable optical switch for the TM mode. Typically, depending on the liquid crystal used and the waveguide geometry, the TM mode in the waveguide can be 'turned' on or off by applying 0V or 10V respectively.

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References

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