

On-Chip Molecular Scale Patterning and Assemblies

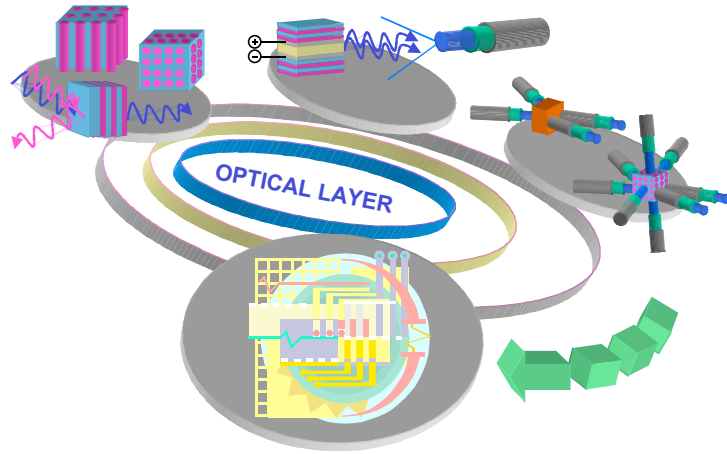
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Project Objectives [1]:

Photonics is a "disruptive" technology, that is, one that has the potential to completely revolutionize entire industries. As a result, the manipulation of light has become increasingly important in many aspects of technology. Polymer microphotonics permits the ready production of precision optical devices or elements using low cost materials and simple processing steps. Rapid advances in this field will be made by the creation of 1, 2, and 3 dimensionally periodic photonic materials with finely tuned optical properties and block copolymers are an ideal material for accomplishing this. By employing block copolymers either as photonic crystals to confine light in the waveguide structure or as the waveguiding element it is possible to form unique optical materials with widely tunable properties [2]. Using these materials one can selectively create low loss, active and passive materials. Passive elements include photonic crystals, conventional waveguides, filters, gratings, interconnects, optical glue and optical resonators. The schematic is an idealized drawing showing how self-assembled block copolymers can play a central role in future optical chips. Depicted are filters, edge emitting lasers, liquid crystal switches and photonic crystal multiplexers.



Switchable Photonic Bandgap Materials

One of the important goals of this research has been to investigate strategies for the creation of active photonic bandgap materials. Our focus on block copolymers (BCP) provides us with a versatile platform to incorporate active components that permit switching of the optical properties of polymer films.

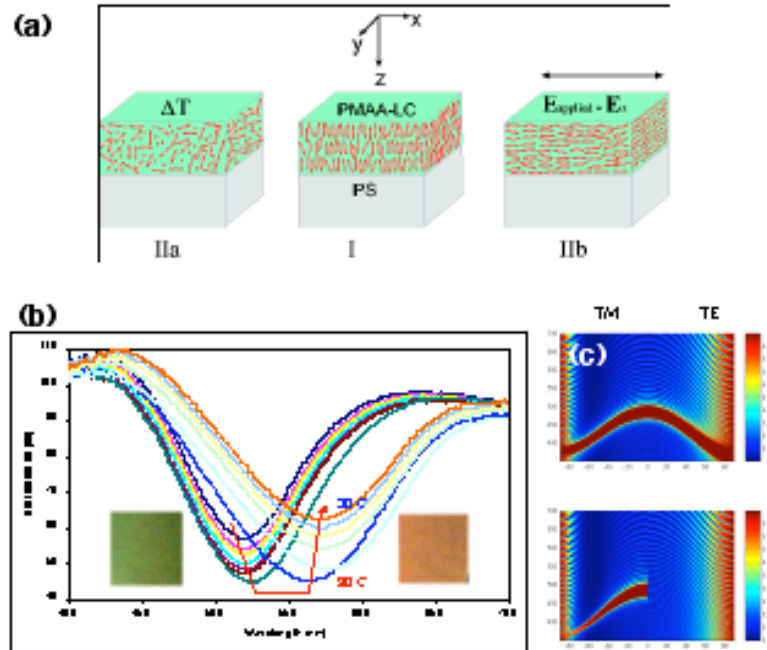
(i) Thermochromic PBG Materials via Mesomorphic Inclusions: For initial work, we chose the simplest microdomain structure, namely a 1D periodic lamellar structure with alternating layers in our case of poly(styrene) and a poly(methacrylic acid) H-bonding LC mixture [3]. We have shown that LC block copolymers can self assemble by simple solvent casting into the re-

quired 1D lamellar microdomain structure with a 175 nm period. We have recently demonstrated thermochromic bandgap switching in which the multilayer stack changes from ordered LC layers at lower temperature (I) to disordered (i.e. isotropic) layers at high temperature (IIa) [4]. The index difference results in a color shift as seen in (b) changing from green (525nm) into the red (575nm). Our present objective is to use applied electric fields (IIb) to change the orientation of the LC components and to alter the refractive index properties of the layers. Computational predictions (c) show that this would be an extremely effective way to alter the PBG properties of this material.

As we are better able to tune the PBG behavior of these materials through new chemistries for greater index of refraction variation as well as field switching of mesogens, we will work with our collaborators to integrate these structures into on-chip devices. Both heat and electric fields will be used to dynamically manipulate the index contrast presented to incident polarized light by a periodic BCP photonic crystal if one of the microphases

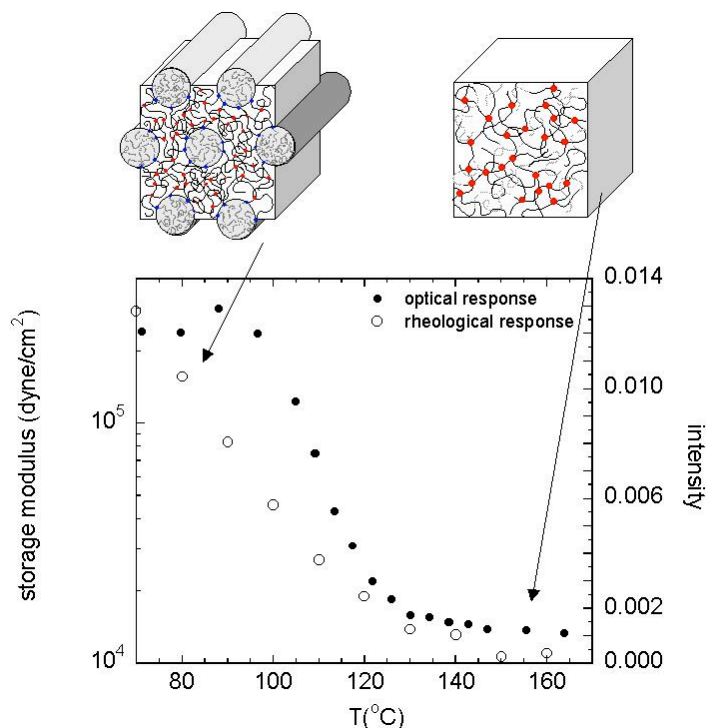
is liquid crystalline (LC). Particularly interesting is the case in which the index of the PS domain is matched by that of the extraordinary component of the PMAA-LC domain. It results in the functioning of the material as a polarizing filter, (see inset, part c) as TM modes within the band gap are reflected while TE modes are allowed to propagate. When successful, these polymers will permit integration of these materials directly into an active device.

(ii) Thermally activated PBG Films and Structures: The use of mechanical forces also provides tools for changing the optical properties of PBG materials [5]. Block copolymers exhibit reversible order-disorder transitions. However, the disordered state is a liquid and this precludes applications that require solid materials. In order to better manipulate the polymer in a form that can be optically useful, we have produced a new kind of polymeric solid by *cross-linking* one of the blocks of a block copolymer in the disordered state. We find that at sufficiently low cross-linking density, the chains can still exhibit a reversible order-disorder transition (ODT). The inset (next page) shows the storage shear modulus and birefringence of a crosslinked polystyrene-polyisoprene copolymer. The temperature dependent rheology and birefringence data shown in the figure correspond to the ODT. These new polymers are easily coated on a variety of substrates by simple spincoating processes prior to crosslinking. Local photopatterning will enable ready device integration. By trapping these microstructures by soft network formation, these new materials have shape memory character. Coupled to selective heaters, these materials have the promise of forming optical lens arrays with controllable focus or photonic bandgap materials with selective wavelength properties.



Future:

We envisage photonic devices that will involve self-assembled components and hybrid lithographic-self assembled structures that are simple to make and inexpensive. Among the advantages of polymer microphotonics include very facile processes for forming waveguides and interconnects. This may involve low temperature solution and melt based processing such as inkjet printing, conventional and soft lithography and organization by means of topographical patterning. Polymers are well suited for high performance photonic devices as well as disposable, recyclable and single use products.



References:

- [1] <http://www.ccmr.cornell.edu/~ccy/nirhome.htm>
- [2] Y. Fink, J. N. Winn, S. Fan, C. Chen, J. Michel, J. D. Joannopoulos, E. L. Thomas, *Science* 1998, **282**, 1679.
- [3] Osuji, C. O.; Chen, J. T.; Mao, G.; Ober, C. K.; Thomas, E. L. "Understanding and Controlling the Morphology of Styrene-Isoprene Side-Group Liquid Crystalline Diblock Copolymers", *Polymer* (2000), **41(25)**, 8897-8907
- [4]. Chinedum Osuji, Chi-Yang Chao, Ion Bitu, Christopher K. Ober, Edwin L. Thomas, "Temperature Dependent Photonic Band Gap in a Self-Assembled Hydrogen Bonded Liquid Crystalline Diblock Copolymer", *Adv. Functional Mater.*, in press.
- [5] Hyeok Hahn, Hany B. Eitouni, Nitash P. Balsara, John A. Pople, "Responsive Solids from Cross-linked Block Copolymers", submitted to *Physical Review Letters*.