Photoexcited 2-Dimensional Photonic Crystal and Quasicrystal Lasers with Organic Gain Media

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Note: This work was performed in collaboration with M. Ibanescu, A. Mekis, M. Meier, J. Joannopoulos, R.E. Slusher, and D. Tennant. The experimental portion was performed in Bell Laboratories, Murray Hill, NJ and the theory portion at MIT, Cambridge, MA.

Photoexcited solid-state organic lasers have been made with a wide variety gain media including dye-doped polymers, dye-doped molecular single crystals, diluted conjugated polymers, neat films of conjugated polymers, and molecular solids. These gain media have been included in a fascinating array of resonators to obtain laser action.

We have used organic thin-film gain media to study laser action in two-dimensional photonic crystals and quasi-crystals. The photonic crystal structures employed, although two-dimensional, do not possess a complete two-dimensional band-gap. The structure of lasers examined is shown in Fig. 1. A coating of photoresist on thermally oxidized silicon is patterned to form a triangular lattice of holes with a typical radius of 100nm. The photolithography was performed with a 248 nm light source giving the pattern a periodicity of 400 nm. Shallow holes of 20-40 nm depth are etched in the SiO_2 by reactive ion etching through the photoresist mask. The photoresist is removed and a film of 2-(4-biphenylyl)-5-(4-tertbuylphenyl)-1, 3, 4-oxadiazole (PBD) doped with about 1% by weight of coumarin 490 and DCM is deposited over the entire structure by spin coating. The structure resembles a planar waveguide with the organic layer as the core with thickness 150 nm and the SiO_2 as the cladding. Lowest order transverse electric (TE) and transverse magnetic (TM) modes are supported.

A pulsed nitrogen laser with pulse width 2 ns and 337 nm light is used to photo-excite the structure. A charge coupled detector (CCD)/spectrometer is used to measure the emission spectra. The PBD molecules absorb the pump and funnel the excitation to the DCM dye molecules through cascade Förster transfer. The gain medium can be approximated by a four-level system.

The typical spectra are shown in Fig.2. The emission takes place above a threshold pump power of ~ 50kW/cm^2. This is significantly higher than the ~1kW/cm^2 required for third order DBR lasers with the same gain medium. This is attributed to the lack of a complete gap that results in a coupling between the lasing mode and other modes localized in the organic.

The 2-D photonic quasicrystals possess a layer structure and fabrication sequence similar to the photonic crystals describes above. A Penrose tile pattern of dots in photoresist is defined by electron beam lithography. Shallow etching of the SiO_2 produces the quasicrystal, which was coated with a gain medium consisting of PBD doped with about 1 % by weight of Coumarin 490. The emission spectrum upon photoexcitation with a

nitrogen laser is shown in Fig. 3. The spectrum shows clear evidence of stimulated emission and possible laser action. The peak wavelength of the emission is close to the theoretically calculated wavelength. The use of alternate gain media (such as a green emitting dye doped into the same host) did not yield spectral narrowing indicative of stimulated emission. This implies that that stimulated emission is not due to random lasing which has been observed in many systems; but rather, is related to the spatial arrangement of dots in this structure and the resultant perturbation of the refractive index in two dimensions.

Additional work needs to be done to prove that the emission observed is indeed laser action. This preliminary report suggests that the use of organic gain media are a very promising way to study laser action in photonic quasi crystals.

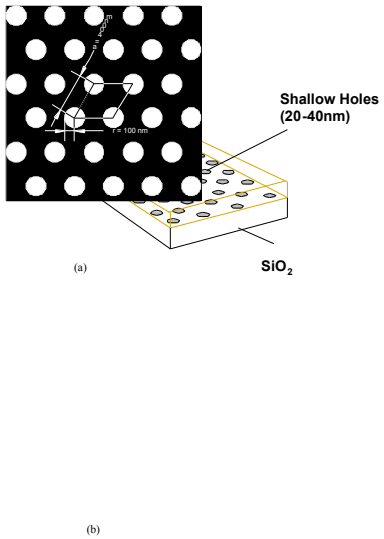

Fig. 1 Schematic structure

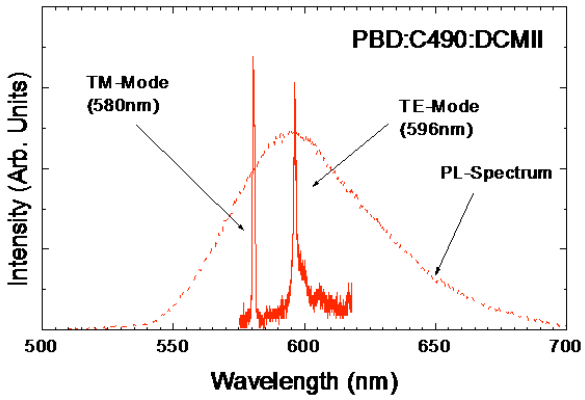

Fig. 2 PL spectrum and laser emission from a 2D Photonic crystal with a triangular lattice

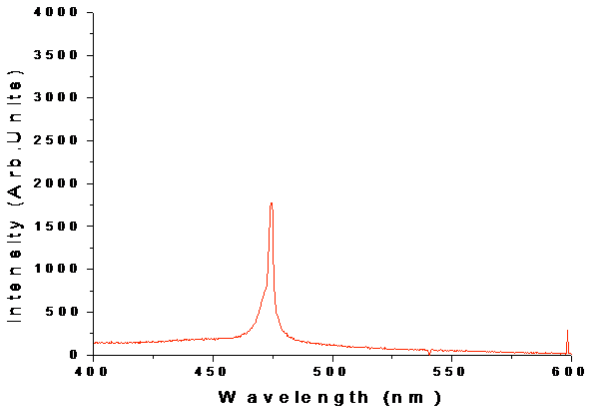

Fig. 3 Stimulated emission from a 2-D photonic quasi crystal