Light Localization in Disordered Photonic Crystals

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Abstract:
We are investigating photon confinement in disordered photonic crystals (PhCs). Our approach involves structural perturbations which are distributed uniformly throughout the artificial crystal by deliberately changing shapes and orientations of the lattice elements. The nanometer-scale disorder created in this way represents random scatterers which impede propagation of extended Bloch-waves through the otherwise periodic lattice. Slow-modes guided along line-defects in disordered crystals experience strong backscattering which results in photon localization. The effect is observed in a narrow band close to the guided mode’s cutoff where the interaction with disorder is strongest.

Research Summary:
High-refractive-index slabs with two-dimensional arrays of air-holes exhibit large photonic bandgaps for the TE-like polarization, which established them as a popular platform for designing waveguides and nanocavities. Engineered PhC nanostructures guide and confine light remarkably well by relying on Bragg reflections in the crystal plane and on total internal reflection in the vertical direction. Guiding losses and cavity $Q$ factors are believed to be limited primarily by the fabrication-induced surface roughness which breaks the PhC periodicity and destroys coherence by diffusive scattering. Considerable efforts have thus been expended to improve fabrication processes which, together with the progress in design optimization, have produced highly-dispersive (or slow-light) waveguides [1,2] and optical nanocavities with ultra-high $Q$s and record-low modal volumes [3].

We have shown that random departures from index-periodicity of bulk PhCs do not necessarily destroy localized defect modes, but can produce a fundamentally different type of coherent photon localization analogous to that observed in strongly-scattering random media [4,5]. Line defect PhC waveguides with structural perturbations in the form of randomly oriented polygons and ellipses were fabricated and characterized. Confined resonances with $Q$s of $\sim$700,000 and wavelength cubed modal volumes were observed in the vertically scattered spectra. Disordered PhCs are currently being explored for potential applications as low-threshold lasers and ultra-sensitive detectors.

References:
Figure 1: (a) Schematic of the measurement set up. Light scattered vertically out of the photonic crystal plane is analyzed; (b) SEM image of a typical disordered line-defect waveguide.

Figure 2: Spatially-resolved spectra of the vertically-dissipated light. Resonances with various localization lengths are observed at random positions along the disordered waveguide.