Optics in 2023

Plasma Microcavities

Plasma is an ionized state of matter in which light absorption, refractive index and optical gain interact with electric currents and magnetic fields. The synergy between plasma and microphotonics could transform optics by providing an additional knob for electro-optically controlling light. Yet the plasma state's low pressure and large electrical fields have presented challenges to introducing plasmas in optical microresonators.

In recent work, we demonstrated an optical microcavity containing plasma inside.[1] We fabricated a 180-μm silica microbubble resonator[2] with walls thinner than an optical wavelength; filled the resonator with argon plasma; and coupled it to a 1.5-μm laser via a tapered fiber.[3]

Our calculations indicate that the optical mode in the microbubble walls evanescently extends to the inner plasma, so that the plasma's optical absorption and refractive index affect cavity transmission. When the input light is at resonance, the plasma's increasing absorption can take the cavity to its undercoupled regime while the transmission through the cavity increases. In actual experiments, as expected, we measured an increase in the resonator transmission from 5% to 78% when the plasma was ignited. Such absorption-induced transmission is opposite to previously reported coherent perfect absorbers,[4] in which a transparent medium makes a resonator opaque.

When we blue-detuned the pump laser relative to resonance wavelength, transmission changed during a ~5-μs ignition of plasma. The experimental results match a theoretical fit and indicate that plasma's index of refraction drops below one, as is typical for plasma. This represents the first time that refractive index smaller than one has been demonstrated in an optical microcavity.

We also observed the interaction of plasma with magnetic fields, as indicated by dark and light regions in a visible-light photomicrograph. These dark and light regions, generally referred to as striations, indicate magnetic fields that apply forces on the moving charges. The field used to ionize the argon was 0.12 V/μm, which suggests that existing transistor technologies—for example, transistor–transistor logic—can ionize the gas in a 40-μm-scale device.

We believe that the introduction of plasma to microcavities, as demonstrated in our study, could transform optoelectronics by providing an additional phase of matter for electrically controlling light using currents, electric fields or magnetic fields to expand the capacities of semiconductor-based photonics. OPN

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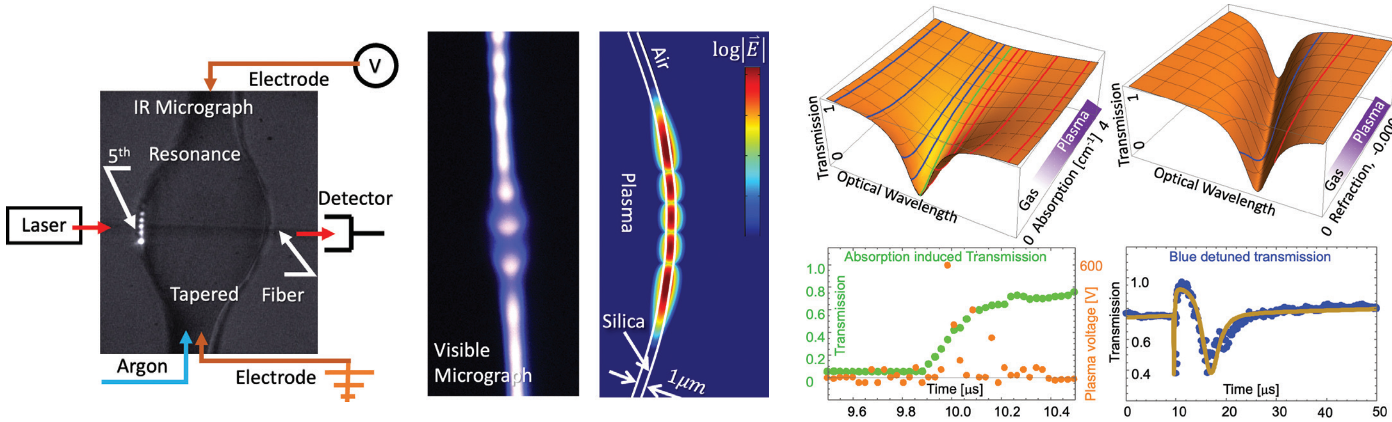

Left: Experimental setup drawn on an IR micrograph of the bubble resonator; resonance is seen via residual scattering. Center: Visible micrograph of the resonator with plasma inside, and calculated optical resonance (colored scale), showing evanescent extension of optical mode into plasma. Light and dark regions on micrograph show interaction with magnetic fields. Right top: Calculated cavity transmission as a function of plasma absorption (left) and refractive index (right). Green line, input light at resonance; blue lines, input light blue-detuned; red lines, input light red-detuned. Right bottom: Experimental results. Cavity transmission when plasma is ignited and the input light is at resonance (left) or blue-detuned (right). Brown line shows theoretical fit, which assumes that plasma density scales with plasma illumination.