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Local tuning of photonic crystal cavities using chalcogenide glasses

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We developed a method to locally tune refractive index in photonic crystals. The technique, based on photodarkening of chalcogenide glasses, enables 3nm resonance tuning of GaAs photonic crystal cavities operating at 940nm.

Photonic crystals represent one of the most promising platforms for on chip integration [1] of optical components. However, they are very sensitive to fabrication imperfection, so a practical method to post-tune their optical properties is needed. Here we present such a method based on chalcogenide glasses. Chalcogenide glasses quasi-permanently change their optical properties when illuminated with light above their band gap, and have been used to tune optical devices as quantum cascade lasers [2]. The tuning of PCs devices directly fabricated in chalcogenide glasses has already been shown in Ref.[3], but many other applications rely on PC fabricated in other materials such as group IV and III-V semiconductors.

In our approach, a photosensitive chalcogenide glass layer is deposited on prefabricated GaAs/InAs devices. Linear three-hole defect [4] PC cavities were first fabricated in a 150 nm thick GaAs membrane containing a central layer of InAs quantum dots (QDs) as described in Ref.[5]. Arsenic trisulphide films with thickness between 30 nm and 100 nm were deposited onto the photonic crystals using thermal evaporation.

The experiment was performed at cryogenic temperature (less than $\sim 60K$) to obtain luminescence from the embedded InAs quantum dots, as needed for quantum information processing applications. This illustrates that the method works at low temperatures, though we stress that it is applicable to room temperature nanophotonic circuits. The sample was placed inside a continuous-flow liquid helium cryostat at 10K and the QD photoluminescence was used to measure the cavity resonance. A confocal microscope setup and a laser tuned at 780 nm excited quantum dot luminescence while a spectrometer monitored the signal. A 543 nm HeNe laser ($1\mu W$) focused to $\sim 1\mu m^2$ through the same confocal setup was used for photodarkening of the As_2S_3 layer (Fig.1). This wavelength was chosen because it is close to the 527 nm bandgap of As_2S_3.

The thickness of the As_2S_3 influences both the quality factor of the cavity and the maximum tuning range. For this reason we experimented with three different thicknesses: 30, 60 and 100 nm (samples S30, S60 and S100). For each sample, the spectrum of the cavities was recorded before and after the deposition of the chalcogenide layer. For samples S60(S30), the deposition caused the quality factor to degrade by $\sim 5\%(30\%)$ from an average value of $\sim 8500(10000)$ while the resonant wavelength shifted by ~ 40 nm(28 nm). For sample S100 the Q degradation was more severe, from ~ 6500 to ~ 1000 and for this reason we mainly concentrate on samples S30 and S60.

With the chips mounted in the cryostat, we focused the 543 nm laser on the PC cavities for a fixed time and recorded the cavity spectrum. For sample S60, the cavity resonance shifted by up to 3 nm as shown in Fig.2(a). For $1\mu W$ of green laser power focused on a spot size of $\sim 1\mu m^2$, the cavity tuning rate levels off after about 20 minutes, as shown in Fig.2(b). This saturation time is inversely proportional to the energy flux incident on the sample surface. During the tuning process the quality factor degraded by 20%. The maximum tuning range dependends on the thickness of the chalcogenide layer. For 30 nm and 100 nm, a tuning range of 1 nm (Fig.2(b)) and 4 nm was observed, respectively. The change of the cav-

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ity resonance was stable after the green laser was turned off.

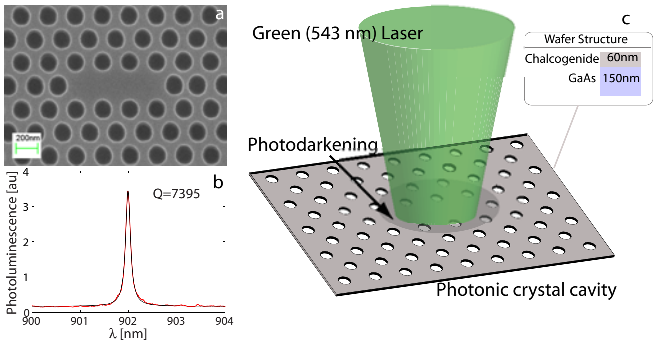

FIG. 1: (a) Scanning electron microscope image of the photonic crystal cavity fabricated in GaAs before the deposition of As_2S_3. (b) Cavity spectrum before the chalcogenide deposition indicating a quality factor Q=7395. (c)Schematic of the method for local cavity tuning. A layer of As_2S_3 is deposited on top of the photonic crystal cavity. Then a laser tuned close to the As_2S_3 band gap is focused on the cavity, increasing the effective refractive index and causing a resonance red-shift.

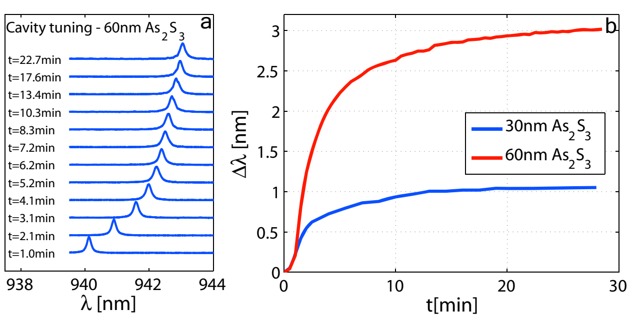

FIG. 2: (a)Spectra showing the shift of the cavity resonance because of the photodarkening of the 60 nm thick chalcogenide layer. (b) Time dependence of the cavity resonance for 60 nm and 30 nm As_2S_3 during the tuning process.

For our experiment, the smallest area that can be locally tuned is limited by the focus size of the laser beam ($\sim 1\mu m^2$). The locality of the technique allows for independent tuning of interconnected optical components on photonic crystal chips. The method is not only suitable for GaAs devices, but can possibly be implemented with any other materials, including silicon nanophotonic circuits. Also, the As_2S_3 can easily be replaced by other types of chalcogenide glasses or other photosensitive materials depending on the specific application.

In conclusion, we have shown that As_2S_3 can be combined with semiconductor photonic crystals to create nanophotonic devices whose optical properties can be independently fine-tuned on the same chip. This technique is relevant for fabrication of integrated nanophotonic circuits for classical and quantum information processing, including applications such as filtering, multiplexing, optical storage, fine-tuning of modulators and lasers, and local tuning of distinct PC cavities on GaAs/InAs chips for quantum optics.

Financial support was provided by ONR Young Investigator Award, the MURI Center for photonic quantum information systems (ARO/DTO program No. DAAD19-03-1-0199) and NSF Grant No. CCF-0507295. Work was performed in part at the Stanford Nanofabrication Facility of NNIN supported by the National Science Foundation under Grant ECS-9731293. CUDOS is an Australian Research Council Centre of Excellence.

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