Embedding and Combining Plasmonic Elements and Photonic Crystal Structures

J. Probst[a], M. Schoengen[a], N.Nüsse[a], J. Wolters[b], B. Löchel[a], O. Benson[b]

[a] Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, Institut für Nanometeroptik und Technologie, Albert-Einstein-Str. 15, 12489 Berlin, Germany
[b] Humboldt-Universität Berlin, Institut für Physik, AG Nano-Optik, 12489 Berlin
e-mail: Juergen.Probst@helmholtz-berlin.de

Photonic crystals represent a new class of optical materials allowing us to tailor photonic behavior through micro patterning. The first to mention the basic ideas were Yablonovitch and John[1] in 1987 and since then, photonic crystals have been subject to intensive investigation. They promise to lead to numerous new applications in photonics or sensor technology since one can actively affect their optical properties. The level of light confinement in photonic crystal structures enables the creation of extremely compact, highly efficient photonic elements such as filters[2], beam splitters[3] or sharp bend waveguides[4], as well as optical resonators for low-threshold lasers[5].

We focus on silicon nitride (Si_3N_4) for production. It has a sufficiently high refractive index and is highly transparent in the visible light spectrum. This ensures large photonic band gaps and high q-factors. Electron beam lithography and reactive ion etching, both used in the production process, allow structure sizes below 80 nm, thus enabling us to produce photonic crystals with a lattice constant in the dimension of half the wavelength of the visible light spectrum. HZB's high end lithography tools allow us to fabricate overlay structures[6] with an accuracy below our detection range. In this way, we can lithographically integrate metallic structures into photonic crystals that serve as plasmonic-photonic hybrid systems (cf. Fig. 1).

In strong collaboration with the Nano Optics Group of Humboldt University Berlin, we focus on coupling the photonic crystal resonators to a variety of different emitters (cf. Fig. 2). Recently, we fabricated plasmonic-photonic hybrid systems by integrating gold antennas into photonic crystals (cf. Figs. 3 and 4). Interferences between the resonances of the photonic crystals and the plasmonic gold antennas could be caused by systematically variating the gold antenna's sizes, allowing us to measure light-matter coupling as well as nonlinear effects such as plasmon induced transparency with fluorescence spectroscopy.

---

1 E. Yablonovitch, Phys. Rev. Lett. **58,** 2059 (1987); S. John, *ibid.* **58**, 2486 (1987)
2 A. Gomyo, J. Ushida, and M. Shirane, Thin Solid Films **508**, 422–425 (2006)
3 H. Chien, C. Chen, and P. Luan, Optics Communications **259**, 873–875 (2006)
4 P.F. Xing, *et al.,* Opt. Commun. **248**, 179 (2005)
5 M. Loncar, T. Yoshie, A. Scherer, P. Gogna, and Y. Qiu, Appl. Phys. Lett. **81**, 2680 (2002)
6 N. Nüsse, M. Schoengen, M. Barth, B. Löchel, W. Eberhardt, and O. Benson, in *Proceedings of the Dornbirner Mikrotechniktage 2010, Dornbirn 2010*

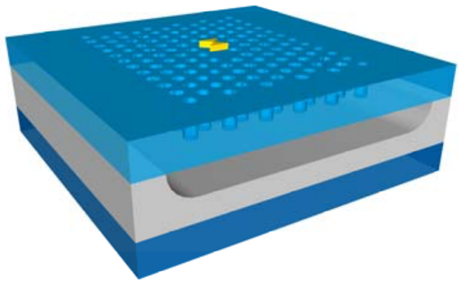

Figure 1: Diagram of a gold bowtie structure embedded in a silicon nitride photonic crystal. The substrate consists of a layer of silicon nitride on silicon oxide (light gray) and silicon (dark gray). The silicon oxide layer is removed beneath the photonic crystal by isotropic etching.

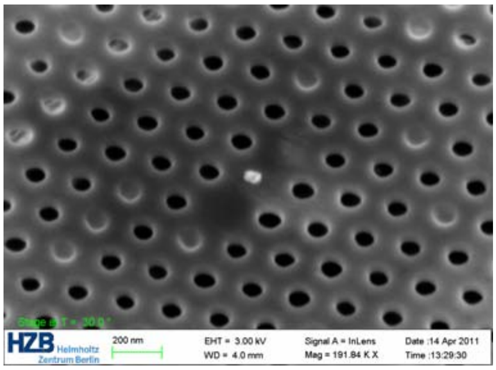

Figure 2: Diamond nano emitter deployed in a L3 cavity of a gallium phosphate photonic crystal. The underlying silicon layer was removed beneath the photonic crystal by isotropic etching.

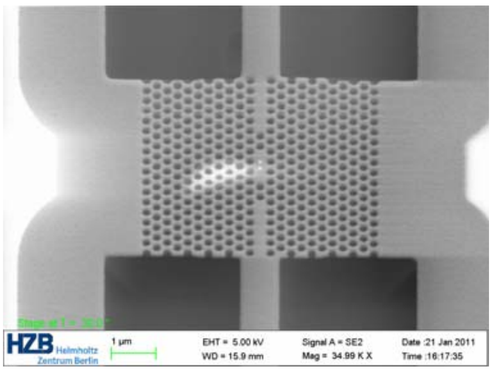

Figure 3: SEM image of fabricated plasmonic-photonic hybrid system. A gold bowtie structure is embedded in a silicon nitride photonic crystal. The bright area left of the antenna is a charging effect pointing to a change in the local electron emission behavior.

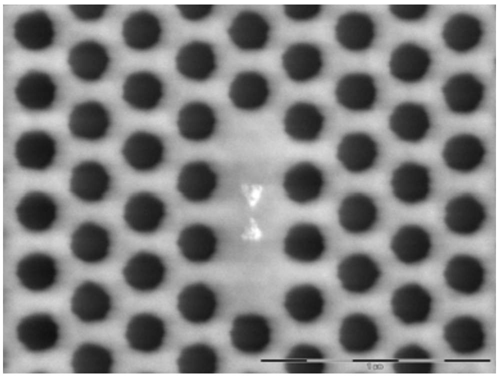

Figure 4: Close-up view of a gold bowtie structure like in Fig. 3. The gold structures were manufactured with varying sizes, orientations and gap sizes.