# Subwavelength Nanopatch SiN/Au Nanocavities with Colloidal Nanocrystals

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We present subwavelength nanopatch cavities with colloidal quantum dots (QDs). These cavities, depicted in Fig. 1b and Fig. 1c, consist of luminescent material (QDs embedded in a SiNx matrix in our case) sandwiched between two metallic surfaces. They allow the confinement of optical resonant modes in subwavelength volumes of the order of $10^{-3}$-$10^{-4}$ $\lambda^3$. From FDTD simulations, high Purcell factors of 10-100 are expected, despite the metal losses and resulting low Q-factors. Previously, lasing at 1.3µm was reported in 500nm-sized nanopatch cavities of a similar design in which the gain material was a bulk InGaAsP layer [1] instead of a QD layer in a SiNx matrix. Our cavities are smaller (a diameter of 100 to 300 nm), designed for emitting at 620 nm, and more lossy. Low Q-factors are desirable since colloidal QDs typically show an emission linewidth of 30-40 nm. An advantage of nanopatch cavities is their inherent compatibility with electrical injection from the top and bottom metal layer. Their combination with cheap and engineered light sources such as colloidal QDs would allow for compact, low-cost and efficient lasers, LED and possibly also single-photon sources.

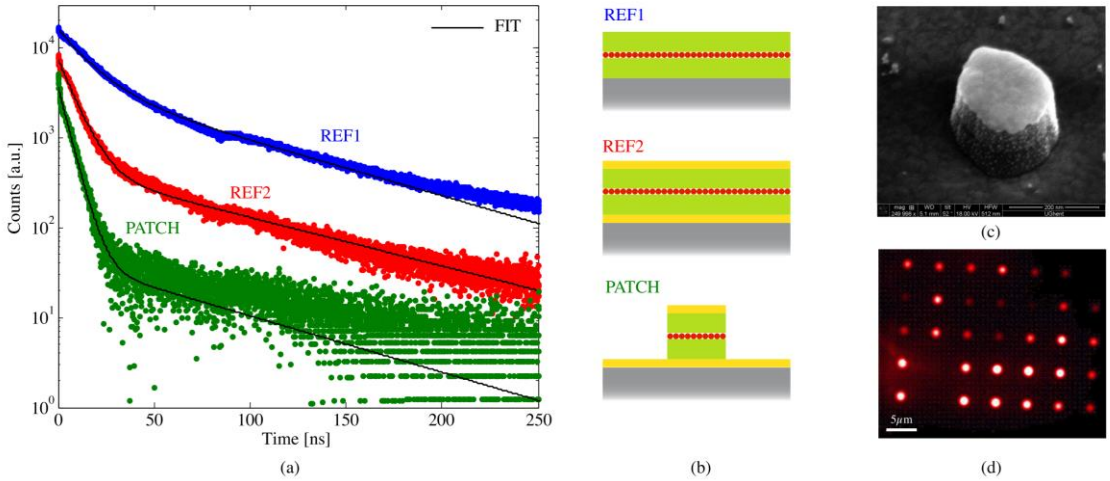


**Fig. 1** (a) Luminescence decay of light emitted from a 300-nm nanopatch (green dots) similar to the one shown in (c) compared to luminescence decay from the reference QD layers (blue and red dots) in (b). (b) Schematic geometry of the nanopatches and of the reference layers (yellow: Au; green: SiNx). (c) Typical nanopatch cavity obtained by our lithographic method. (d) Luminescence from an array of nanopatch cavities under cw excitation at 450 nm.

The cavities were fabricated using a layer-by-layer deposition method, followed by a double-resist lithography to define the nanopatches. A typical cavity is shown in Fig. 1c. The roundness is limited by the resolution of the e-beam. We used CdSe/CdS colloidal QDs emitting at 620 nm. They were synthesized using the method described in [2].The nanopatch cavities were designed and using FDTD methods such that the wavelength of the $TE_{011}$ mode matches 620 nm. For a cavity height of 120 nm, the mode wavelength was shown insensitive to the cavity diameter in the 200-400 nm range. A Q-factor of 30 and a Purcell factor of 10 are expected. Fig. 1d shows the luminescence from an array of cavities under cw excitation at 450 nm. The luminescence decay from the nanopatch cavity was investigated. We compared these decay to two reference situations shown in Fig. 1b. In situation REF1 the QDs are embedded in a SiNx matrix. The decay is bi-exponential with a short lifetime $\tau_1$=14.4 ns and a long lifetime of $\tau_2$=70.56 ns (see Fig. 1a, blue dots) in line with measurements in solution. When the QDs are sandwiched between two layers of Au (situation REF2), we observe a reduction of the shortest lifetime ($\tau_1$=8ns), but no change in $\tau_2$ (see Fig. 1a, red dots). Tests on nanopatch cavities of 300nm show further shortening in good cavities. A lifetime $\tau_1$=5.19 ns was recorded in the best case, corresponding to a 3-times speed-up of the spontaneous emission compared to QDs in a SiNx matrix.

## References

[1] K. Yu, A. Lakhani, and M. C. Wu, "Subwavelength metal-optic semiconductor nanopatch lasers," Opt. Express **18**, 8790-8799 (2010)
[2] M. Cirillo, T. Aubert, R. Gomes, R. Van Deun , Ph. Emplit, A. Biermann, H. Lange, C. Thomsen, E. Brainis, and Z. Hens, ""Flash" Synthesis of CdSe/CdS Core–Shell Quantum Dots," Chem. Mater. **26** , 1154–1160 (2014)

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