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Marcus Albrechtsen [a], Babak Vosoughi Lahijani [a,b], Rasmus Ellebæk Christiansen [b,c], Vy Thi Hoang Nguyen [d], Laura Nevenka Casses [a,b,e], Søren Engelberth Hansen [a,b], Philip Trøst Kristensen [a,b], Nicolas Stenger [a,b,e], Ole Sigmund [b,c], Henri Jansen [d], Jesper Mørk [a,b], Søren Stobbe [a,b]

[a] Department of Photonics Engineering, DTU Fotonik, Technical University of Denmark, Building 343, DK-2800 Kgs. Lyngby, Denmark
[b] NanoPhoton - Center for Nanophotonics, Technical University of Denmark, Ørsteds Plads 345A, DK-2800 Kgs. Lyngby, Denmark
[c] Department of Mechanical Engineering, Technical University of Denmark, Nils Koppels Alle, B. 404, DK-2800 Kgs. Lyngby, Denmark
[d] DTU Nanolab, Technical University of Denmark, B. 347, DK-2800 Kgs. Lyngby, Denmark
[e] Center for Nanostructured Graphene, Technical University of Denmark, 2800 Kgs. Lyngby, Denmark
E-mail: maralb@fotonik.dtu.dk

Photonic nanocavities achieve tight temporal and spatial confinement of light through the quality factor, Q, and the mode volume, V, respectively. This results in local enhancements of the electric field, $\mathbf{E}$, which is central to a number of applications requiring enhanced light-matter interaction [1], such as nonlinearities [2] or efficient optical interconnects [3]. Previously, it was believed that the mode volume in dielectrics was bound by the diffraction limit [4], and therefore field enhancements were achieved by large quality factors [5]. With the recent discovery of dielectric bowtie cavities, however, mode volumes deep below the diffraction limit are possible in devices with nanometer-scale features [2,6]. Such features, in turn, pose challenges to the resolution of fabrication at the deep nanoscale.

Here we investigate the importance of precise pattern design and the effects of rasterization (shot-filling) in electron-beam lithography when pushing the resolution limit. We consider a novel nanocavity design obtained by inverse design using tolerance-constrained topology optimization [6] in which the local density of optical states (LDOS) is optimized at the very center of a silicon cavity to have $Q = 1100$, $V = 0.08\ (\lambda/2n)^3$, and $\lambda = 1551$ nm.

To illustrate the importance of shot-filling for high-resolution electron-beam lithography, we first consider the test structure shown in Fig. 1. The contours between material boundaries are used to define a set of polygons as shown in Fig. 1**a**. Individual patterns are well separated to be isolated from long-range proximity effects [7]. Figures 1**b** and **d** show the fracturing of the polygon as well as the discretization into individual shots separated by a pitch, p, and exposed with a uniform dose density, D. This means that the impinging charge dose of each shot (in coulomb) is $q = p^2D$. Electron-scattering through the material broadens the point-like exposures along with the other process steps, here development and etching, to yield an effective deposited dose density, D_{eff}, shown on the grayscale map in Figs. 1**c** and **e** [7-8]. The regions that receive an effective dose density greater than the dose to clear, D_0, will be developed as indicated by the green contour. Figure 1**c**, shows visible line-edge roughness caused by the coarse discretization and poor dose uniformity, which, for a cavity, can cause substantial optical loss through scattering (reduction in Q) [5], while the finer discretization in Fig. 1**e** produces much smoother edges and a higher fidelity in the pattern transfer due to the finer discretization.

Figure 2 shows three nanocavities fabricated with the same process on the same chip where the current, and therefore pitch, is varied. Already when the pitch is increased from 1 nm to 3.5 nm, several of the small features cannot be resolved, and with $p = 6$ nm the central part becomes disconnected, thus charging up under SEM inspection. We will report on our latest progress towards realizing structures with extreme confinement of light.

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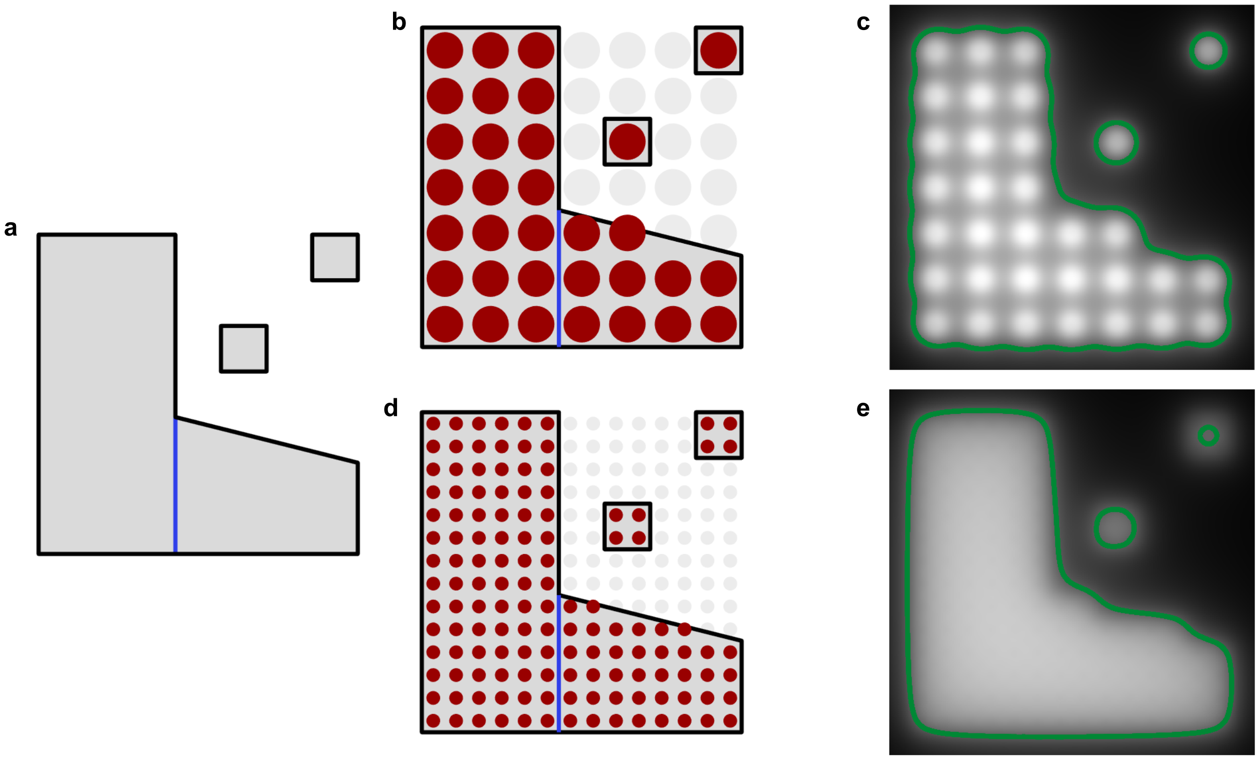

Figure 1. Schematic showing effects of shot-filling. a, Polygon mask with blue line representing a cut polygon due to fracturing. **b**, Shot-filling with a large pitch. **c**, Convolution between shots in **b** and a measured point-spread function [7]. **d**, Shot-filling with a smaller pitch, and **e**, convolution between shots in **d** and the point-spread function. The green outline shows the contour $D_{\mathrm{eff}} \geq D_0$.

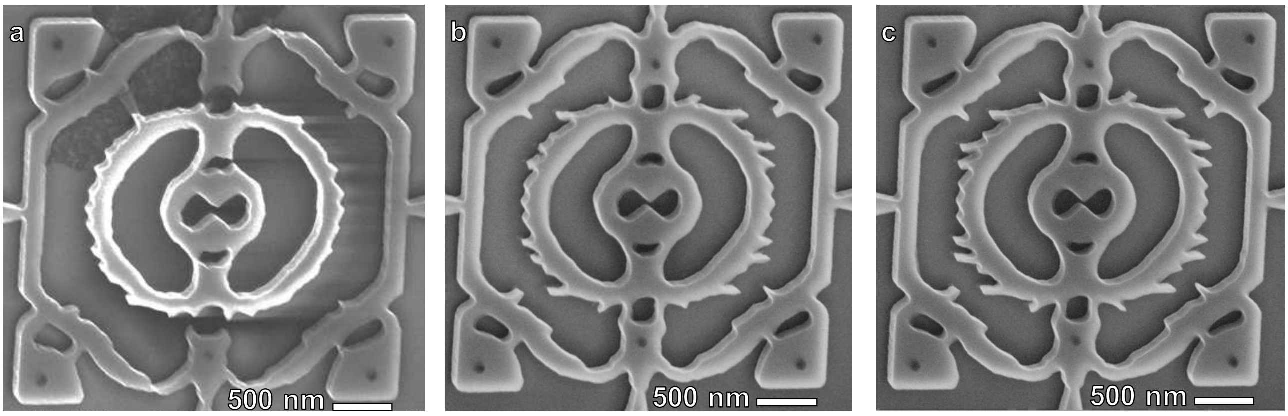

Figure 2. Topology optimized photonic nanocavity fabricated with different e-beam rasterization. The structures are fabricated with the same process except the current is varied and with it, the pitch. **a**, $p = 6$ nm and $I = 6$ nA. **b**, $p = 3.5$ nm and $I = 2$ nA. **c**, $p = 1$ nm and $I = 0.2$ nA. The pattern-transfer fidelity is significantly improved with a smaller pitch.