

Patterning of electrically tunable, light-emitting photonic structures made of erbium doped zinc oxide

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We report a scalable process to fabricate electrically tunable, light-emitting photonic structures made of optically-active and electrically-conductive erbium doped zinc oxide (Er:ZnO) deposited by magnetron sputtering. Such structures are expected to produce a dramatic enhancement of the electromagnetic fields due to enhanced light-matter coupling at distinctive topologically protected states called Bound States in the Continuum (BICs).

Er:ZnO thin films (175 nm \pm 5 nm thickness) were deposited via RF magnetron sputtering at room temperature in Ar atmosphere. Post-deposition thermal annealing was performed in a furnace at 900 °C for 60 min in oxygen atmosphere. Excitation at 488 nm produced room-temperature photoluminescence (PL) in the IR range with peak at 1550 nm. PL lifetime was measured to be \sim 3.8 ms. (Fig. 1)

Er:ZnO thin films were patterned with electron beam lithography and inductively coupled plasma (ICP) etching. As shown in Figure 2, ICP etching through a resist mask (ZEP520A) resulted in a rough Er:ZnO layer. The roughening of the material was found to be due to the UV radiation generated during the plasma etching. To circumvent this problem a metallic mask (10 nm of chromium) was used (Fig. 3). The sample was first covered with a 3 nm layer of SiO₂ deposited by atomic layer deposition (ALD). This layer was necessary to protect the Er:ZnO from dissolution by amyl acetate, which is used to develop ZEP. A \sim 150 nm poly(methyl methacrylate) (PMMA) layer was spin-coated on the ALD SiO₂ followed by a 10 nm Cr layer deposited by electron beam evaporation. A \sim 500 nm layer of ZEP was spin-coated on the Cr, and baked at 100°C instead of the conventional 180°C, to prevent the multilayer structure from cracking. Finally, Aquasave was spin-coated on the ZEP to serve as discharge layer during the e-beam exposure. The Cr mask was ICP etched at 20°C using a mixture of Cl₂ and O₂. The PMMA was removed with O₂ reactive ion etching (RIE) while the thin ALD SiO₂ was removed with CHF₃ and O₂ RIE. Er:ZnO was ICP etched using a mixture of CH₄, H₂, and Ar at 20°C. The etching process produced a fairly straight etch profile; the etch rate was found to be ten times slower than for plain ZnO under the same etching conditions^{1,2}. The PMMA layer allowed for the Cr mask removal by lift-off in Remover PG (the use of chromium etchant would result in the complete dissolution of the Er:ZnO).

We demonstrated a scalable process to pattern photonic structures made of Er:ZnO. Optical characterization studies are being performed.

¹ K. Ip, et. al. Solid-State Electronics 47 (2003) 2289-2294.

² J. S. Park, et. al. J. Vac. Sci. Technol. B 21(2) (2003) 800-803.

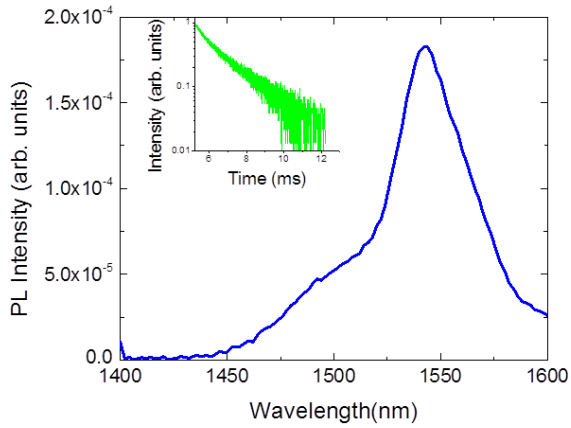


Figure 1. PL spectrum of unpatterned Er:ZnO (after annealing). Inset: PL lifetime at peak frequency (1550 nm).

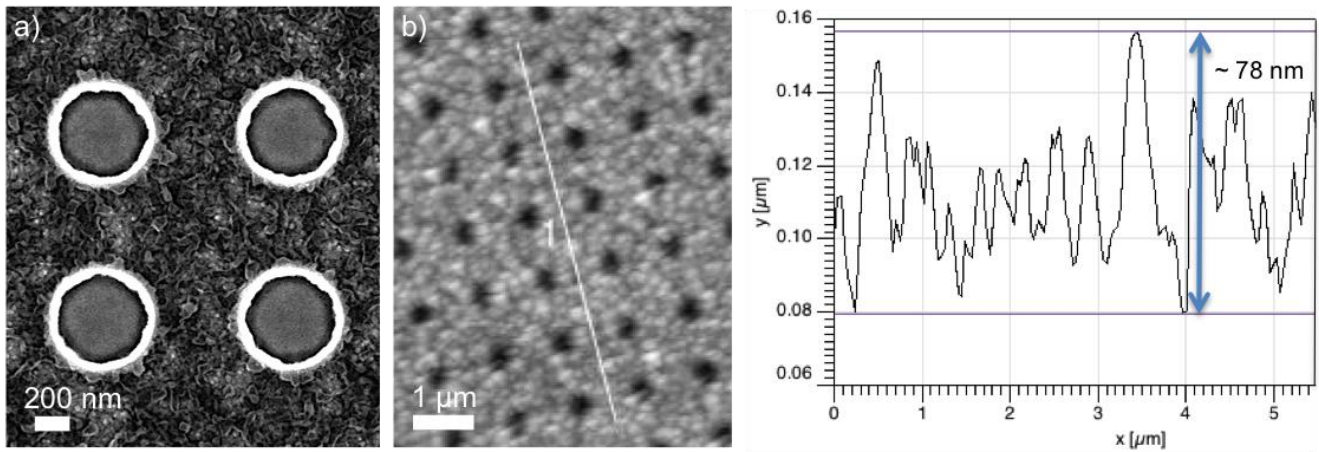


Figure 2. Er:ZnO (~ 175 nm thick) after ICP etching through a resist (ZEP) mask. a) SEM image. b) AFM image and profile showing increased roughness (100 nm range).

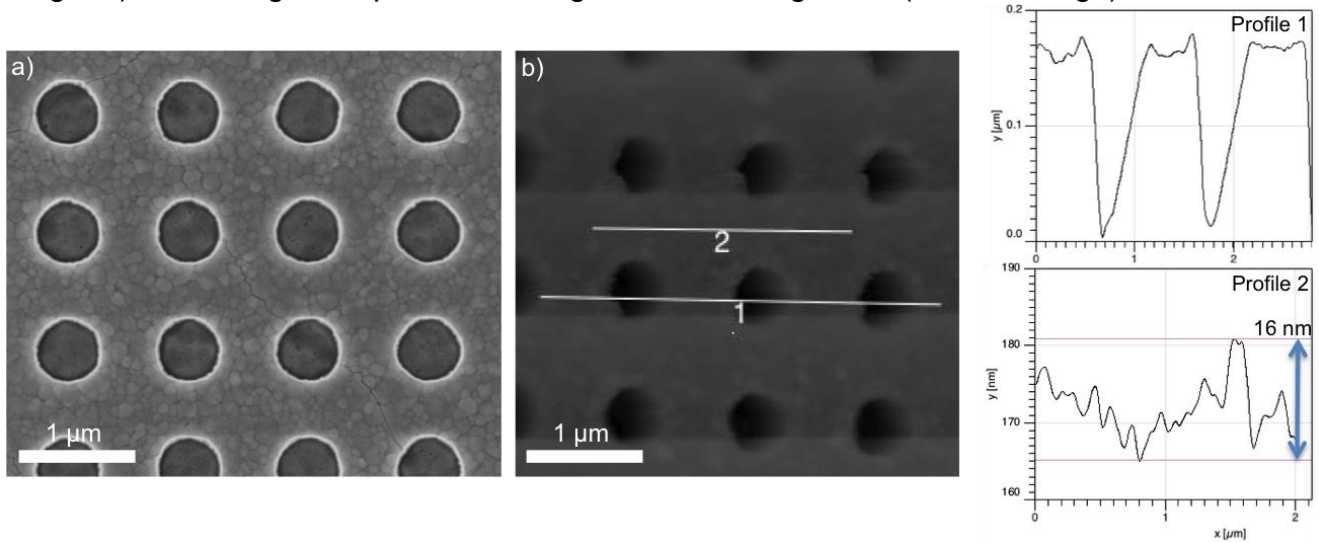


Figure 2. Er:ZnO (~ 175 nm thick) after ICP etching through a chromium mask. a) SEM image. b) AFM image and profile showing roughness in the 10 nm range.