Fabrication of Plasmonic-enhanced Nanostructured Electron Source (PNE) Using Epitaxial Lift-off and Nanoimprint Lithography

Yixing Liang, Yuxuan Wang, Weihua Zhang, Loren Pfeiffer and Stephen Y. Chou
Department of Electrical Engineering, Princeton University

We have proposed, fabricated and tested a new innovative photocathode, termed Plasmonic-enhanced Nanostructured Electron-source (PNE), that offers many advantages over the conventional photocathodes, including sub-picosecond electron pocket pulse width, ultra-high quantum efficiency, small longitude and transverse emittance, sub-diffraction limit spot size, and long photocathode life-time.

The PNE comprises an ultra-thin nanoplasmonic cavity and inside a thin photoelectron active material layer with short carrier lifetime (Fig. 1) [1]. The special thin active layer shortens electron pocket pulse width to sub-picosecond, while the plasmonic cavity increases the photon absorption by 405%.

We have successfully fabricated the PNE using epitaxial lift-off and nanoimprint lithography (NIL) as shown in figure 2 (b). The fabrication has 4 key steps (Fig. 2): (1) 100 nm thick GaAs thin film was grown using MBE at low temperature (250 ^{o}C) on bulky GaAs substrate with a 50 nm thick $Al_{0.85}Ga_{0.15}As$ sacrificial layer grown in between; (2) Au meshes with 200 nm period hole arrays were patterned on the low-T grown GaAs film using NIL and lift-off; (3) the low-T GaAs thin film were separated from bulky substrate using epitaxial lift-off. The film thickness of low-T GaAs can be thinned with nanometer precision; and (4) the lift-off thin film was bonded onto Au back-plane to complete the fabrication of PNE.

The light reflection spectrum in Fig. 3 (a) shows that PNEs with 40 nm thick LT-GaAs and 140 nm diameter hole Au meshes have an absorption of 77% at 800 nm (the wavelength of Ti:sapphire pumping laser). By contrast, the measured absorption at 800 nm is only 30 % for 40 nm thick LT-GaAs on gold film and 7% for a planar gold film, leading to an estimated absorption in a 40 nm free standing of 19 %. Therefore the PNE has increased light absorption by 257% and 405 % respectively, compared with the same LT-GaAs film with an Au backplane or a free-standing of such film. The strong absorption is attributed to local plasmonics, which absorbs and traps light inside the cavity, as shown by simulation (Fig. 3(b)).

A pump-and-probe experiment with a fempto-second laser shows that the photoelectron lifetime in the PNE is 0.3 ps, which is the key for picosecond pulse width electron pocket.

The light absorption and trapping can be further improved by optimization (e.g. 93% light absorption at 670 nm wavelength light has been achieved in 100 nm thick LT-GaAs and 170 nm diameter hole Au meshes). The architecture and fabrication of PNE can be utilized to improve the performance of other photocathodes.

[1] S. Y. Chou, unpublished, 2010

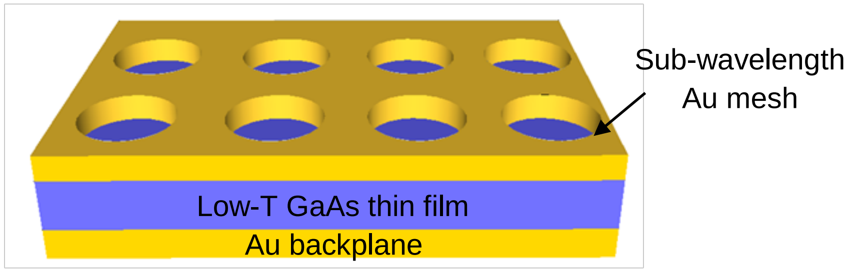
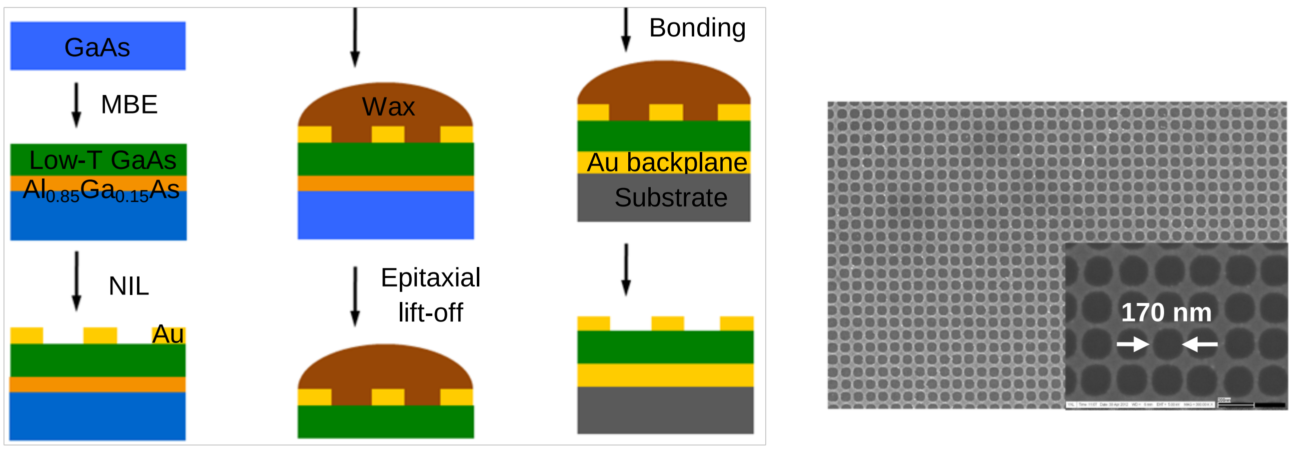
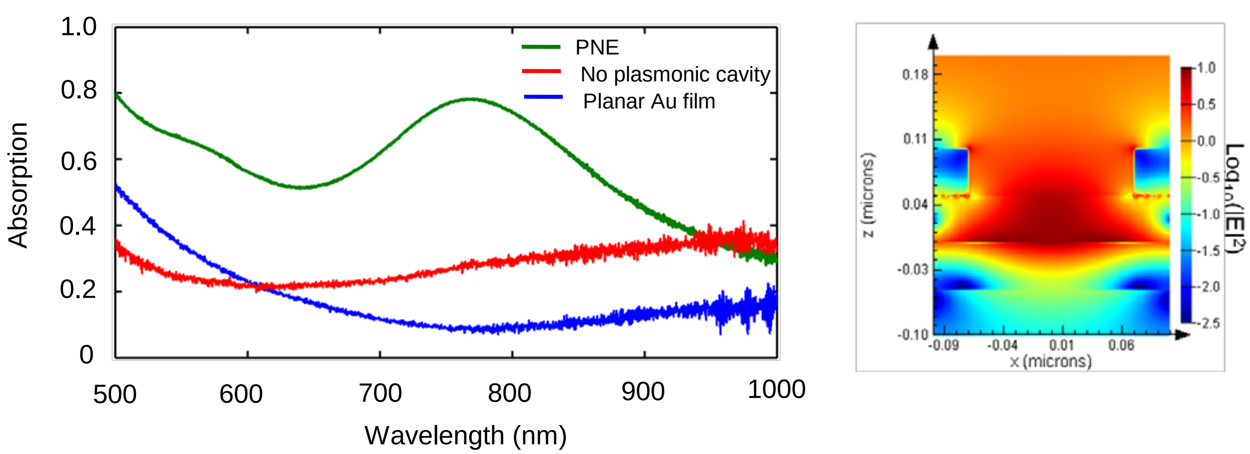


Fig. 1. Structure of PNE



(a) **(b)**

Fig. 2. (a) Schemes for fabrication process of PNE (b) SEM images for 170 nm Au mesh on PNE



(a) **(b)**

Fig. 3. (a) Measurement results showing PNE has 77% absorption at 800 nm (b) Simulation result demonstrating local plasmonics focuses and traps light field.