Nanofabrication of high aspect ratio and 25 nm wide Au nanostructures using low-temperature development of PMMA and pulse electrochemical deposition

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Au nanostructures with high aspect ratio (HAR) and nanoscale features are of great importance in microscopy, microtomography, spectroscopy and many others.[1,2] Nanofabrication of these structures still faces challenges in both patterning resist molds and filling Au in deep trenches.

Here, a nanofabrication process of Au patterns with aspect ratio up to 12 and feature size down to 25 nm is demonstrated using low-temperature development of polymethyl methacrylate (PMMA) and pulse electrochemical plating. To pattern resist mold, thick PMMA resist on silicon nitride membranes coated with seed layer of Cr (5 nm) and Au (10 nm) was exposed using a 100 kV electron beam writer (JBX-6300FS), and was developed at 4 degrees Celsius. The simulation result shows that the broadening of the electron beam is less than 3 nm and the backscattering effect can be ignorable. Furthermore, the low-temperature development results in a high resolution and a large contrast, leading to a small blur in development. To improve the height uniformity of Au nanostructures formed in deep and narrow trenches, the off duration of the pulse current in Au electrochemical deposition was prolonged to 198 msec and the on duration was fixed as 2 msec. The prolonging of the off duration enhances the recovery of the diffusion layer near the cathode with different feature sizes, and thus leads to a uniform height for both large and small features (see Fig. 1). Under proper conditions of lithography and Au deposition, 25 nm wide and 300 nm high patterns were achieved (see Fig. 2). A transmission electron microscope was also utilized for characterizing the nanoscale Au walls and their grain textures as shown in inserted image in Fig. 2., indicating that poor joints between the seed layer and Au nanostructures are most likely to cause reliability problems. The demonstration of this straightforward process would benefit to nanofabrication of HAR Au nanostructures and their wide applications.

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[1] J. Vila-Comamala, V. Guzenko, R. Mokso, M. Stampanoni and C. David, Microelectronic Engineering 87, 1052 (2010).

[2] J. Liu, J. Shao, S. Zhang, Y. Ma, N. Taksatorn, C. Mao, Y. Chen, B. Deng, T. Xiao, Simulation and experimental study of aspect ratio limitation in Fresnel zone plates for hard-x-ray optics, Applied Optics 54, 9630 (2015).

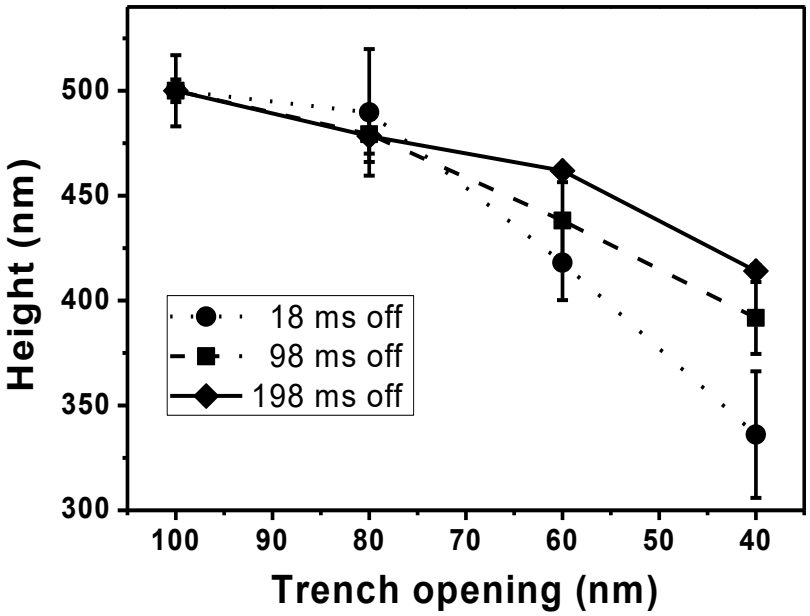

Figure 1: The effect of off duration of depositing current on the uniformity of height of Au patterns with different features.

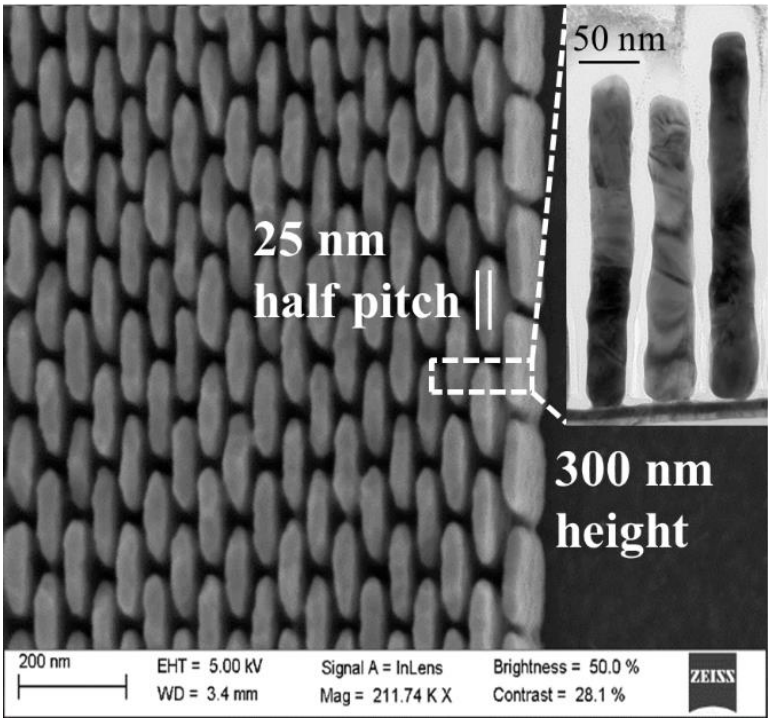

Figure 2: 300 nm thick and 25nm wide half pitch formed by means of electron beam lithography and Au pulse electrochemical deposition. The inserted image in top right corner shows the joints at the bottom and the grain textures of Au nanostructures.