Ultra high aspect ratio X-ray photon sieves by deep reactive ion etch on silicon and electroplating

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X-ray lens, such as Fresnel zone plates (FZPs) or photon sieves, are advancing toward high resolution and high efficiency for microscopy of materials to support the basic research in almost all the science and technology discipline. In this scenario nano-lines or nano-holes with high aspect ratio (width/height) is fundamentally needed, but it is limited by proximity effect in electron beam lithography (EBL). The theoretical limit of aspect ratio is merely 20 for a 100 nm zone plate [1] for the application in X ray energy below 9keV. On the other hand, for the application in hard x-ray beyond 10keV, metallic nanostructures taller than 2 μm are still technically impossible. To break through this bottleneck, an alternative approach rather than traditional EBL for high aspect ratio replication is urgently needed.

In this paper, we report our recent progress in fabricating nanoscale photon sieves with thick Au layer and high aspect ratio by deep reactive ion etch (DRIE) on silicon followed by Au electroplating.Photon sieves with the appropriate distribution of pinholes over the Fresnel zones (Fig .1) have better spatial resolution and lower backgrounds than FZPs with the same specific minimum feature size. Figure 2 schematically illustrates the process flow for the fabrication of photon sieves with submicron resolution. Nanoscale Cr dot array as the etch mask is formed by EBL and metallization. The key procedure in this process is to achieve nanoscale and ultra tall Si pillars by an anisotropic etch based on a time-multiplexed inductively coupled plasma process (Bosch process), using SF_6 for etching and C_4F_8 for sidewall passivation.Au electroplating is finally carried out to form desired photon sieves. Systematic study, as presented in table 1,2 and figure 3, has been conducted for optimizing processing condition such as Boshcycle time, flow of gasses and RF power, aiming at achieving absolute verticality with nanoscale sidewall roughness by minimizing scallops. Figure 4 presents 7μm tall and vertical Si pillars (Fig.4a) with 14 nm sidewall roughness (Fig.4b), which can be further reduced by oxidation/wet etch process. Figure 4d shows 13μm tall Si pillars achieved.

In conclusion, a solution for achieving tall and ultra high aspect ratio in X-ray sieves for high diffraction efficiency by DRIE process has been demonstrated. The vertical sidewall with nanoscale roughness in Si pillars as template for Au photonsieves indicates this technique is promising for new brand of X-ray components. This technique should also find applications in fabricating zone plates, light collimators, gratings, Kinoform lens and compound refractive lens in hard X-ray beyond 10 keV.

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[1] Jianpeng Liu, Jinhai Shao, Yifang Chen, Applied Optics.54, 9630(2015).

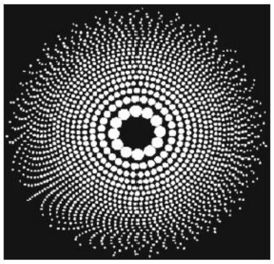

Figure 1.The profile of photon sieves.

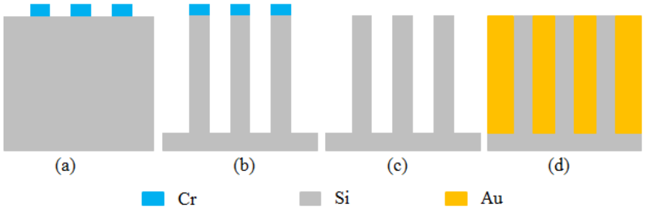

Figure 2.Process flow for the formation ofphoton sievesby DRIE: (a) Cr mask on Silicon; (b) DRIE; (c) Metal removal; (d) Au electroplating.

$t_{Passivation}$ / $t_{Etching}$	Scallops (nm)	Profile (°)
7:12 (0.6)	130	76
5:8 (0.6)	81	78
3:5 (0.6)	14	88

Table 1. At same ratio between passivation and etching time, effect on sidewall scallops and etching profile with shorter cycle time.

$t_{Passivation}$ / $t_{Etching}$	Scallops(nm)	Profile (°)
5:6 (0.8)	80	82
5:7 (0.7)	82	82
5:8 (0.6)	81	78

Table 2. Effect on sidewall scallops and etching profile with different ratio between passivation and etching time.

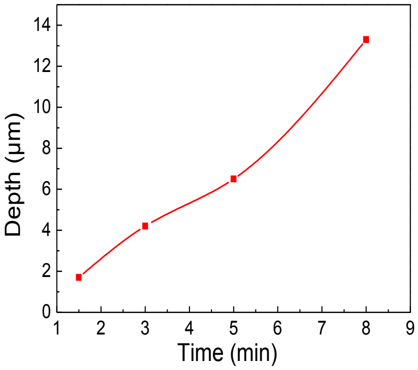

Figure 3.Effect on etching depth with differentetching time.

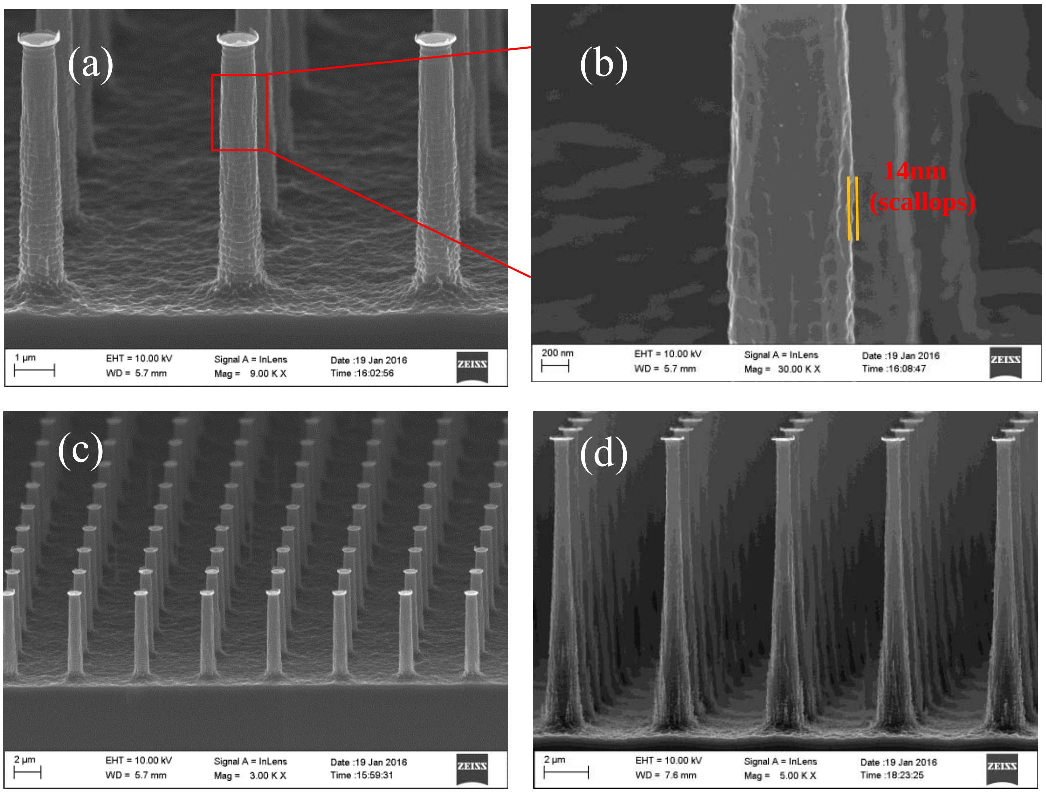

Figure 4. (a) SEM image after 5 min DRIE; (b) Magnified SEM image of the sidewall roughness in (a) ; (c) Global view after 5 min DRIE; (d) SEM image after 8 min