Multilayer on-chip stacked zone plates with high aspect ratio for hard X-ray nanoscale imaging

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Hard X-ray Fresnel zone plates offer an excellent combination of high spatial resolution, acceptable efficiency, easy alignment and energy tunability for spectroscopic studies. They are key optical elements for nanoscale focusing and imaging of hard X-rays. The outermost zone width dr_N (the minimum linewidth of a zone plate) sets its spatial resolution, so it poses interesting challenges in e-beam lithography. The diffraction efficiency is set by the thickness of the zones, so that one must develop processes that can produce high aspect ratios.

Conventional zone plates fabricated by simple nanotechnology process are limited by the achievable aspect ratios. On-chip stacking[1] allows the realization of a single zone plate with very high aspect ratio, which improves the focusing efficiency for hard X-ray microscopy. As an example, for 20 keV X rays 570 nm thick binary Au zone plate would have a theoretical diffraction efficiency of 2.0%, while doubling the thickness to 1.14 μm would yield 7.4%. While multiple zone plates can be mechanically stacked to give high efficiency with hard X rays[2], single zone plates are still easier to use and do not require alignment adjustment.

Experimentally, we fabricated a double layer on-chip stacked zone plate made of gold. It measures 1.14 μm thick and has 100 nm finest zone period (50 nm dr_N and 50 nm space), which achieves a very high aspect ratio up to 23:1. The nanofabrication process is a multi-step process which involves the combination of high resolution e-beam lithography on poly (methyl methacrylate) resist, development, reactive ion etching, electroplating and multilayer alignment. Alignment marks were used during e-beam lithography for the on-chip stacking. Figure 1 & 2 show SEM images of the focused ion beam prepared cross-section of the outermost zones of a double layer on-chip stacked gold zone plate which measures dr_N=50 nm and 100 nm period. Some parts of the zones are collapsed due to its high aspect ratio. The images show that there are almost no mismatches in between single layers; thus the overlay accuracy is very high. Multilayer on-chip stacked zone plate offers a path to high aspect ratio which allow us to get to higher spatial resolution and higher focusing efficiency.

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[1] S. Werner et al., Nano Research 2014, 7(4): 528-535
[2] S-C. Gleber *et al.*, *Optics Express* 2014, 22(23): 28142-28153

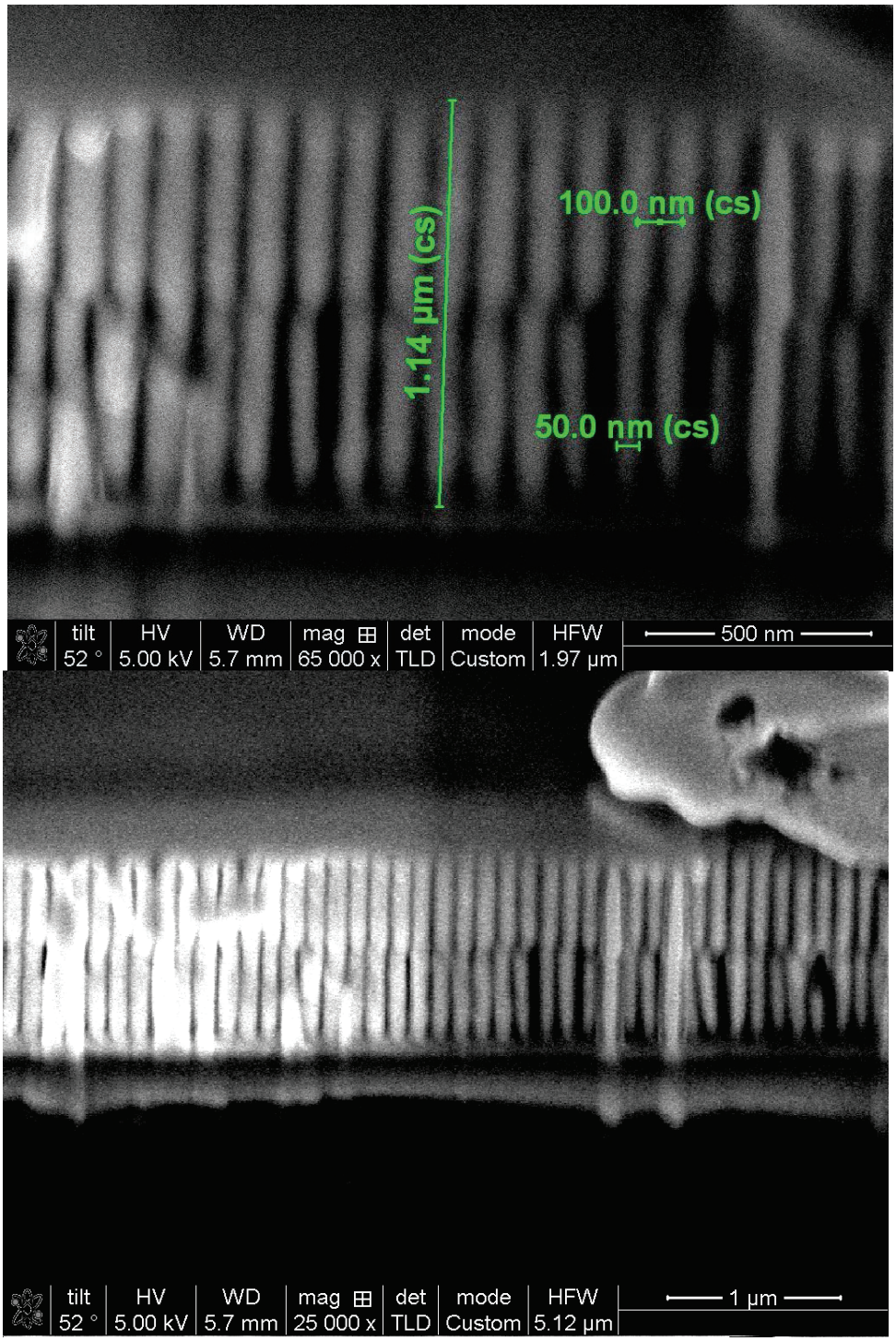

Figure 1 & 2: On-chip stacked zone plate: SEM images of FIB cross-section of a double layer on-chip stacked zone plate with 50 nm dr_N (100 nm period) and a total height of 1.14 µm. The corresponding maximum aspect ratio reaches up to 23:1. The images show high accurate alignment and almost no mismatches.