# Tilted Etching of Microstructure Arrays via Local Electric Field Modulation

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The anisotropic nature of plasma etching is usually exploited to realize vertical nano-/micro- silicon structures by deep reactive ion etching. However, some applications, such for example, as light coupler for augmented reality waveguide combiners and gratings for X-ray interferometers with lab sources[1], require tilted instead of perpendicular profiles with respect to the substrate.

Here, we demonstrate control of the slant angle during the plasma etching with a conventional etching system (ICP etcher) by introducing one or a set of metal electric field modulator(s), which modify the near sample surface potential (see Fig.1). The ions are accelerated from the plasma body towards the sample substrate, providing a vertical etching profile. The metal electric field modulators bend the ion trajectories resulting in a gained lateral velocity and leading to a tilted etching of the local microstructures. This tilted angle decreases with the distance from the modulators, the closer to the modulator the larger tilted angle.

The role of the electric field modulator thickness and inter-modulators distance on the tilt gradient has been studied with a finite element method. The thicker the electric field modulators and the shorter the inter modulator distance are, the larger is the tilt gradient and the higher the maximum angle. The etching behavior expected from the model has been experimentally verified by fabricating a series of samples with different modulator's parameters. The influence of some critical factors such as the distribution of the bias potential at the substrate has been indicated. The thickness ($h$) and the inter modulator distance ($d$) of a local modulator Al slabs have been varied in a range of 0.5-3 mm and 10-25 mm, respectively, and all the slabs have the same width ($l$) of 5 mm. A tilt angle ranging from 0° to 22.6° has been measured in silicon gratings, showing that a desired tilt profile can be achieved with a proper parameters tuning. Examples of 1D and 2D modulations are reported in Figure 1 with linear and chessboard slanted gratings for X-ray imaging applications.

The new method allows easier and more precise slant modulation with respect to the reactive ion beam etching[2], where etch anisotropy is controlled via the directionality of the ion beam combined with angle of incidence.

1. Shi, Z., Jefimovs, K., Romano, L., Vila-Comamala, J. & Stampanoni, M. Laboratory X-ray interferometry imaging with a fan-shaped source grating. *Opt. Lett.* **46**, 3693-3696, doi:10.1364/OL.426867 (2021).
2. Ip, V., Pearsall, F., Henry, T. & Singhal, R. *Reactive ion beam etch of slanted gratings for augmented reality*. Vol. 11696 PWO (SPIE, 2021).

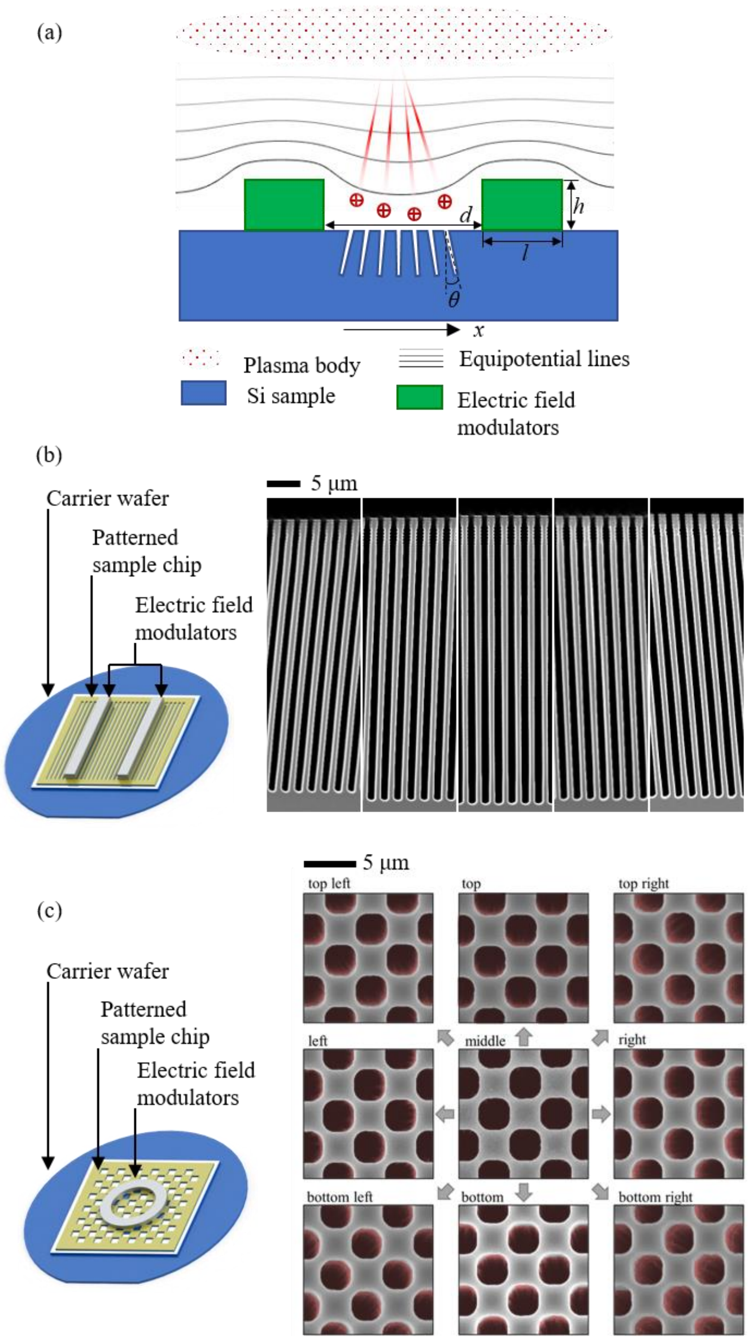


*Figure 1:* (a) The mechanism of the tilted etching method. (b) Schematics of the 1-D tilted etching component arrangement and the cross-sectional SEM image of an etched sample. The period of the silicon lines at the top is 2 µm, and the depth of the trenches is ~40 µm. (c) Schematic of the 2-D tilted etching component arrangement and the plane view SEM image of a real etched sample piece. The width of the holes is 2 µm, and the depth of the holes is ~15 µm.