Fabrication of 22-nm hp silicon lines by single-exposure self-aligned spatial-frequency doubling

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The semiconductor industry will soon require a lithography technology that extends beyond the linear systems limits of traditional single exposure imaging technology with a 193 nm source, even with immersion extensions (~ 30 nm half pitch (hp) at present). Double exposure techniques are being actively investigated. One attractive approach is to print a uniform grating pattern at the smallest possible pitch and then add structural information in a second exposure. We have demonstrated a self-aligned processing sequence involving only a single lithography step followed by a spatial frequency-doubling step that results a half scaling of the original pattern and have achieved a 22 nm hp, which is, to our knowledge, the smallest half pitch ever produced using a 193 nm source.

A maskless, interferometric lithography (IL) approach involving the interference of two coherent beams at a pitch of 89 nm (193 nm source and H_2O immersion) was used for initial patterning and combination of metal masking and anisotropic KOH etching and metal masking step was used for the frequency doubling, resulting in a 22 nm hp pattern, well beyond the optical resolution limit. Importantly this process is applicable to any grating pattern, in particular, it can be applied to smaller hp as higher index fluids become available. Figure 1 shows the process schematically. This technique takes advantage of the well-known anisotropic etching of silicon by KOH and other alkali metal hydroxides. KOH will etch along the (100) crystal plane several hundred times faster than along the (111) plane of silicon. The net result is that if a protective layer is deposited along the (110) direction of silicon (here we use a metal lift-off process) and the sample is immersed in an appropriate KOH solution, V-grooves are etched into silicon through mask openings that terminate in the low etch rate (111) faces. The metal mask is then removed to expose the additional high etch rate surface of the sample again for a second KOH etch, resulting in a pattern at twice the original spatial frequency. Figure 2 shows SEMS of the resulting pattern. The frequency-doubled pitch is 44.5nm; the roughness in the pattern is a result of imperfections induced by the metal patterning at these very small scales. Extensions of this concept to other frequency doubling techniques that do not rely on crystallographic effects will be discussed.

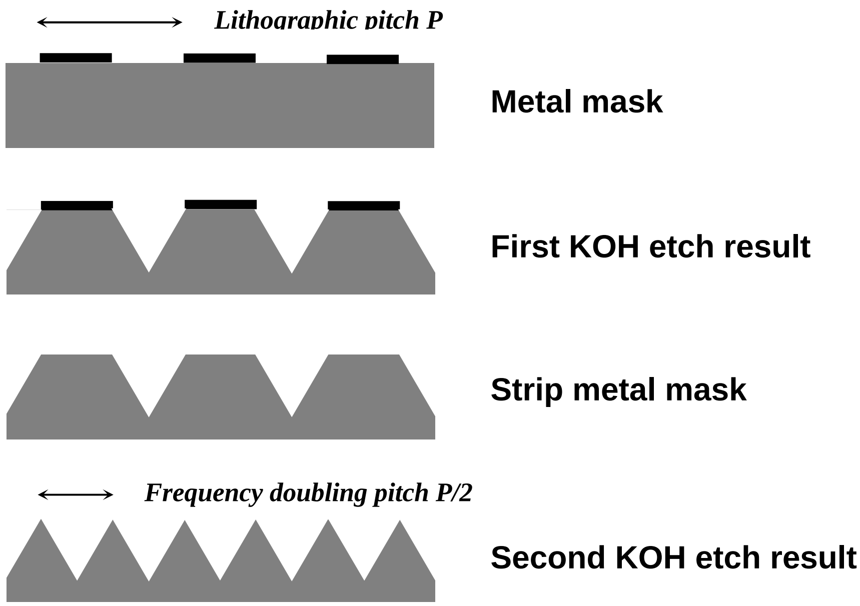

Figure 1. Self-aligned frequency doubling scheme using anisotropic wet chemical etching of silicon.

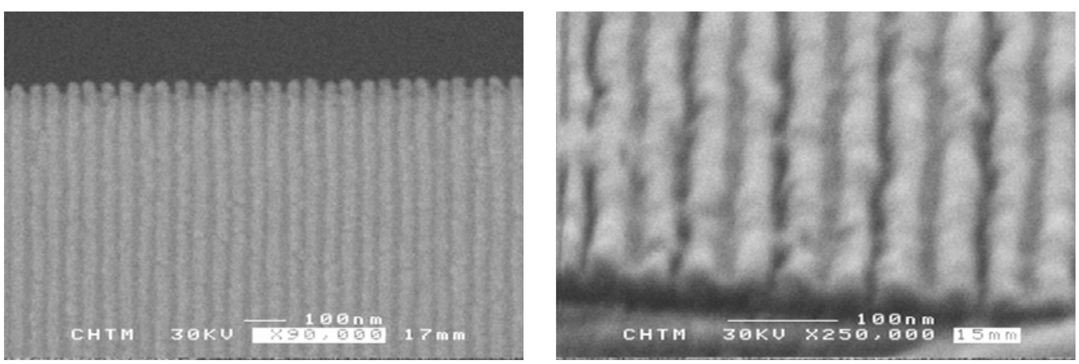

Figure 2. Experimental result demonstrating a frequency doubled 44.5 nm pitch pattern and 22-nm hp lines in silicon.