Deep Silicon Etch Profile Control

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As has been stated in the literature[1], the Bosch process is a well accepted, highly reliable method for producing high aspect ratio features in silicon for the fabrication of advanced MEMS devices. A key attribute of this technology is the flexibility of the process in providing a wide range of etch profiles. This versatility allows for application of the process with a wide range of devices.

Work has been performed to determine the available profile control on a Plasma-Therm ICP system. Characterizations have been performed and significant correlation between independent and dependent variables have been determined. All aspects of the etch profile can be directly controlled with process parameters. These are summarized in the following table:

Result of Bosch Etch Process	***Main Independent Variable that Affects Result***
High Etch Rate	Power levels
Good Selectivity	Gas Composition
Profile Control	Etch/Dep Process Ratio
Notching	Initial Step Parameters

The results obtained from the above can be categorized into a number of areas. Straight wall results can be optimized to obtain re-entrant, vertical, or tapered profiles, with optimization occurring for a number of different size features. Notched profiles, to create an overhang at the top of a feature, are also available. Lastly, rippled topography in the sidewalls can be adjusted in the process. These results are listed schematically in Figure 1

[1] C. Constantine, et. al., "Silicon Trench Etching for MEMS", *Micromachine Devices*, Vol. 2, No. 2, February, 1997.

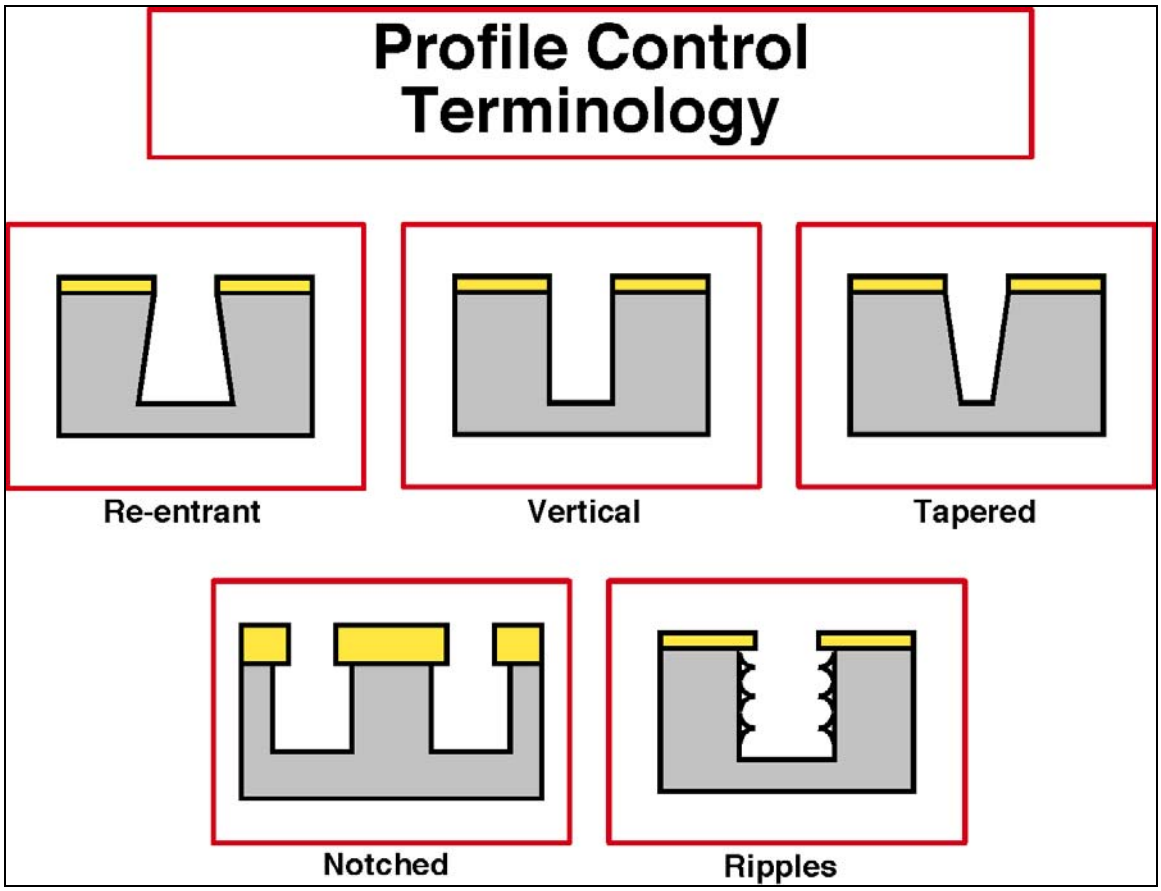

Figure 1-Profile Control Terminology

Applications of these techniques are endless. Typical uses for these different etch techniques include:

Etch Result	***Application***
High Etch Rate	Through Wafer Etching, Membrane Fabrication
Notching	Lateral Tips and Threads
Re-Entrant Profile	Beam Isolation, Thin Tips and Threads
Tapered Profile	IC Trench Isolation
Vertical Profile	High Aspect Ratio Beams and Trenches
High Selectivity	Sub-Micron Features

Examples of these individual results are numerous and were presented earlier at a conference[2]. Samples of this include through wafer actuators (Figure 2), where 3.0 um wide beams are etched through 250 um of silicon. These

[2] F. Bertech, et. al., "Deep Silicon RIE with Profile Control", Presented at the 44th National Symposium and Topical Conferences, Sponsored by the American Vacuum Society, October 20-24, 1997.

features have been integrated into high capacitance change sensors and high force actuators.

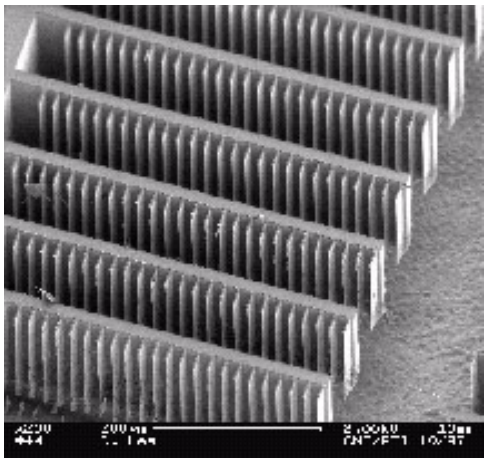

Figure 2

More important than the above individual results is the ability to combine these individual process results to provide application specific features. These can be individually tailored to the needs of the user and, therefore, allow complete flexibility for the device designer. An example of this is for sub-micron beam production. Here, high selectivities and profile control are combined to make a 0.5 um beam 20 um tall. This 40:1 aspect ratio beam (figure 3) can be made even thinner with controlled notching which reduces the actual feature size to less than the lithographically defined mask size. This results in features withi even larger aspect ratios.

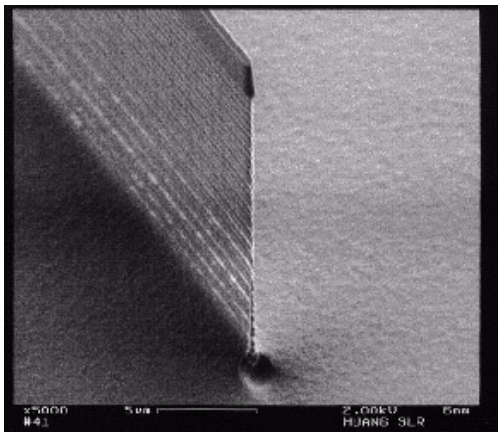

Figure 3

A number of conclusions are drawn from this work. The Bosch process clearly provides high etch rate processes, which have high selectivities. Profile control is available from variation of a number of independent parameters, including process settings and the ratio of dep/etch cycles. These profiles can be

precisely controlled to provide a wide range of results and customized process results. Lastly, it is this flexibility that allows for the integration of deep silicon etch processes into a large number of new devices.