Fabrication of Deep Large Angle Tapered Trenches for Microelectromechanical Applications

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Deep trench silicon etching is one of the principle technologies currently being used to fabricate microstructure devices and is an enabling technology for many microelectromechanical system (MEMS) applications. Strict control of the silicon etch profile is required for these new complex devices to function. Of particular note are deep trenches with a tapered profile, a requirement that has proven to be much more difficult to fulfill than etching a reentrant profile.

Tapered trench profiles make a wide variety of MEMS possible. Two important examples are fiber optic alignment and micromolding. A prescribed arrayed arrangement of fiber optic cables can be accomplished by etching holes in a wafer and then threading the fiber through them. Tapering the entrance to the hole by 5 degrees allows for easier insertion of the fiber through the wafer. Another application of deep tapered trenches is polymer micromolding. Deep trenches that are smooth and tapered are pressed into a softened polymer. The polymer is then hardened and, when removed from the silicon mold, has the inverse shape of the mold. A trench with a rough sidewall or that is not tapered correctly causes the polymer to become stuck in the mold, decreasing process performance or causing process failure.

Currently, the most versatile silicon deep trench etches are based upon cyclic etch-deposition processes. At Applied Materials, this process is known as the time multiplex, gas multiplex (TMGM) process. Unlike traditional etch processes in which all gases are supplied to the etch continuously, the TMGM process cycles between etch and passivation deposition steps, with each cycle removing as much as a micron of material. The TMGM process is favored because it allows for the use of highly aggressive but less directional etchants, such as SF_6, while still providing fine control of the sidewall profile. Polymers such as C_4F_8 are used to coat the trench sidewalls and control the etch. TMGM also offers good wafer uniformity; typically less than 2% on etches as deep as 100 microns. Resist thickness issues are also reduced due to the 150:1 possible resist selectivity and even greater selectivity to hardmasks.

The discrete cyclic nature of the TMGM process lends itself to recipe changes from one cycle to the next. These changes allow for much greater process flexibility, including the ability to etch deep large angle tapered sidewalls, something not possible using previous silicon etch techniques.

A typical process, with only one recipe step, can create a tapered profile. Unfortunately, the maximum taper angle possible using this method is very small and the taper is difficult to sustain for more than a few microns. By tuning the TMGM process to etch more aggressively at the start of the etch, steeper tapers can be achieved.

However, TMGM is not without faults. The cycling of gases introduces a unique type of sidewall roughness known as scalloping. Scalloping occurs because the SF_6 etch is somewhat isotropic. The edge profile of a single etch step is not flat, but rather it is bowed outwards. This shape is then repeated for each additional etch step, resulting in a sidewall with a wavy profile. The etch profile is controlled principally by the aggressiveness of the etch and deposition steps. Pressure, gas flow rate, time, and RF power are all process parameters that can be varied at each process step. Higher pressures typically lead to faster etch rates, but have large scallops. Typically very deep trench etches require pressures of over 150 mTorr if the etch is to be completed in a reasonable amount of time. Gas flow rate and time both affect the residence of etchant or passivation at the etch surface, affecting the taper angle of the etch profile. RF power determines the power of the etching ions is used to control the direction of the RIE.

This paper discusses the parameters that affect an etch profile. Methods of achieving a tapered etch profile with minimal scalloping are explored with an emphasis on in situ cycle variation. Process variation between cycles is extended to a final process step that reduces scalloping even further.