Enhanced High Aspect Ratio Etch Performance With ANAB Technology.

Keywords: High Aspect Ratio, Etch, Neutral Particles, Neutral Beam

I. INTRODUCTION

As device density increases according to Moore's law, three dimensional device features with increasingly high aspect ratios are necessary. Device manufacture involves multiple material deposition cycles combined with lithographic processing of photoresist layers to form patterned masks that protect necessary device layer material while allowing all other material to be selectively removed. Gas phase ion etch reactions, also known as 'dry etch' may be used to perform the selective material removal process. Dry etch technology typically involves halogens such as fluorides, chlorides or other reactive species combined with charged particle technology to form reactive radicals. An ion-assisted reaction is a phenomenon in which the incoming ions enhance the surface reactions [1]. The reactive species interact with target material surfaces forming volatile compounds that are released from the surface and pumped away. High aspect ratio dry etch technology is necessitated when physical sputtering of pattern mask material is the limiting factor for high aspect ratio target material removal. In order to effectively process at increasingly high aspect ratios, the following technology performance criteria must be met:

1) Energy Range: Highly controllable flux energies are required so as to minimize sputtering of mask materials while simultaneously enabling delivery of reactive species to high aspect target locations. Typical particle energies for dry etch applications are less than a few hundred eV.

2) Process Beam Divergence: As aspect ratios continue to increase either by narrowing of the feature width or increasing the feature depth, the likelihood of beam interaction with the feature sidewall increases dramatically. Bowing is a phenomenon in which the etch profile becomes barrel-shaped because of side etching at the middle of the hole caused by scattered ions hitting the sidewalls [2]. Perpendicularity to the feature bottom and homogenous trajectory are necessary to maintain critical feature geometry (sidewall shape).

3) Surface Charge Accumulation: As layer dimensions continue to be minimized, increasingly stringent voltage budget requirements for device fabrication will be required. Gate oxide breakdown is becoming a serious problem as the gate oxides become thinner [3]. Charge accumulation and capacitive breakdowns through insulating device layers greatly reduce process yields. Additionally, it is extremely difficult to control charge accumulations at the bottoms of high aspect ratio features (holes), causing potential for device damage and repulsion of arriving process species leading to process variability.

4) Reactive Species: Reactive gas species must make contact with target material in order to combine and create volatile materials. This is done either of two ways: Either via high concentration background gas incorporation into the process chamber and then irradiation with

the energetic beam to form radicals or alternatively, reactive gas is incorporated into the energetic beam for delivery into the high aspect ratio feature.

Traditional charged particle beams and plasmas combined with chemically reactive species are used to etch material surfaces. However, as aspect ratios continue to increase to 100:1 and beyond, traditional charged particle technologies may be unable to meet these stringent process criteria going forward. Beam blowup is the repulsion of particles of like charge from each other, particularly at low energies such as those required for 'dry etch' processing. For this reason, charged particle fluxes may have divergent trajectories that can further complicate side wall geometries of high aspect ratio features. Surface charging effects on the substrate surface or within the high aspect ratio feature can further exacerbate issues related to charge repulsion effects on sidewall straightness and process repeatability. It is also recognized that the charges associated with ion technologies may ultimately damage device layers due to charge accumulation and capacitive discharging through insulating device layers. Efforts to neutralize the process flux and substrate by addition of neutralizing electrons add process complexity and are difficult to accurately control in high aspect ratio features (see figure 1).

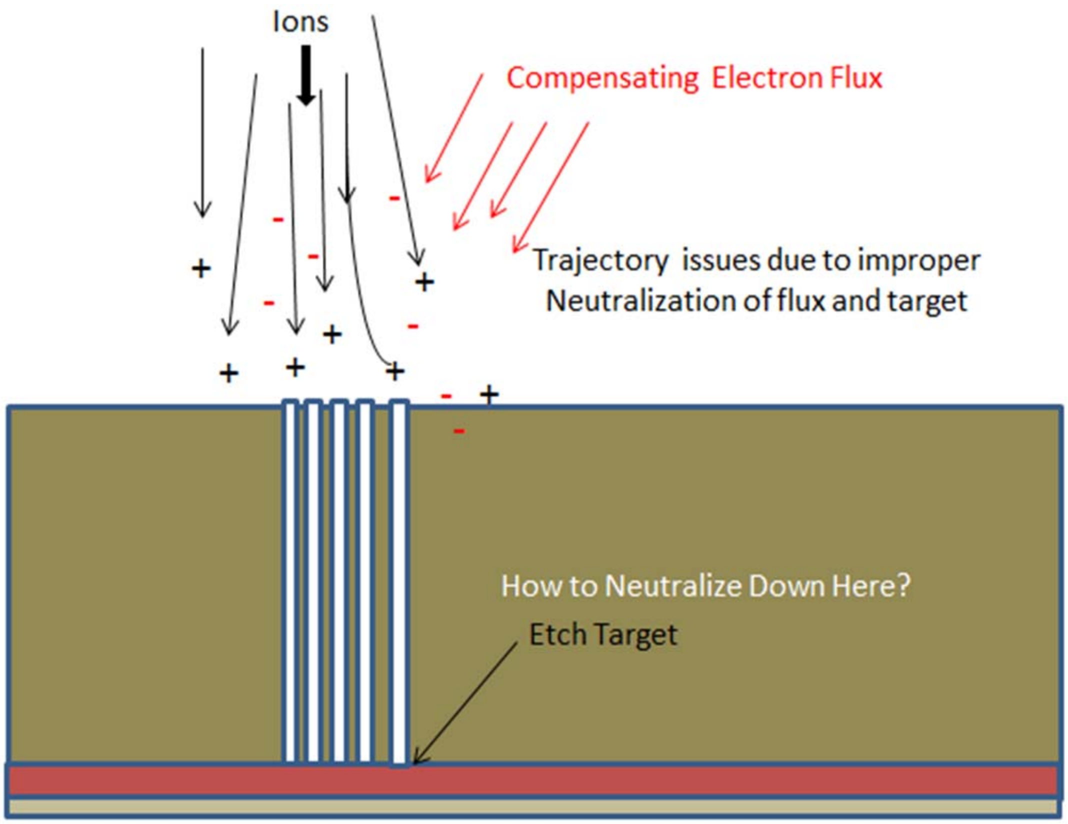

Figure 1. High aspect ratio etching with traditional charged particle technology.

ANAB technology provides intense, highly collimated beams of neutral (never ionized) atoms with adjustable and controllable energies in the range from less than 10 eV to greater than a few hundred eV that are particularly well suited for high aspect ratio 'dry etch' applications for the following reasons: ANAB atoms are not subject to charge repulsion effects and can be transported long distances in highly collimated fashion. This is advantageous for processing at the bottom of high aspect features while minimizing side wall damage and maintaining critical dimensional tolerances. Any gaseous species may be incorporated into ANAB fluxes to be delivered in accelerated form into high aspect ratio features, thereby mitigating the need for high concentration backgrounds of hazardous or corrosive gases, minimizing attack on tool materials and increasing safety. Halogens, for examples, Cl_2, F_2, NF_3 and SF_6 alone or in combination with other species such as N_2, O_2, and CH_4 are readily incorporated into source gases for ANAB generation to form ANAB comprising reactive constituents. ANAB fluxes can process both conductive and insulating layer materials without need for neutralization measures. This greatly simplifies processing and provides for highly repeatable, damage free processing (see figure 2).

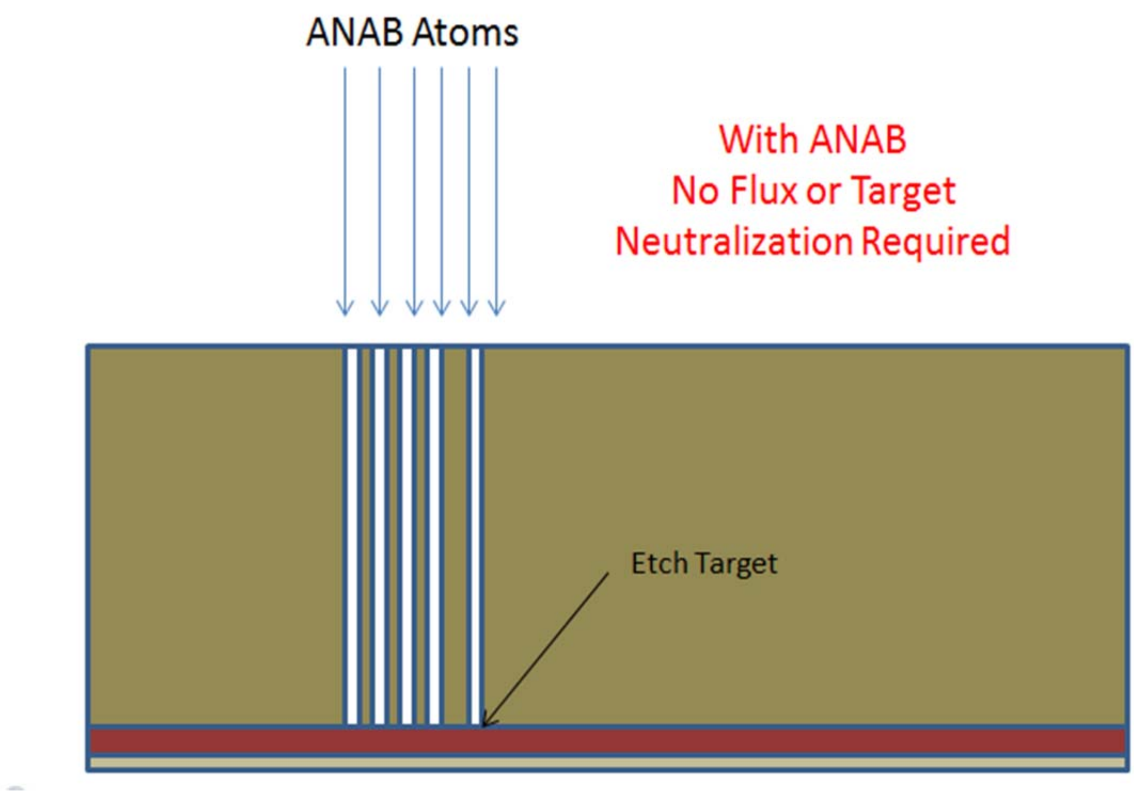

Figure 2. High aspect ratio etching with Accelerated Neutral Atom Beam technology

II. FLUX MEASUREMENTS AND ENERGY CONTROL

ANAB average energies per atom and atom fluxes are characterized by using a fixed orifice device that combines a thermopile to measure total power carried by the beam and an ion gauge pressure sensor calibrated for mass flow to measure the arriving atom flux.

Three approaches are available for controlling the average energy of ANAB atoms. The first is to control the size distribution of the clusters from which the ANAB atoms are generated. Cluster size can be altered by varying the flow of gas through the nozzle, with higher gas flows producing larger cluster sizes. As an example, if a 1000 atom cluster is accelerated to 30 keV, then the energy per atom is 30 eV. Similarly, if a 2000 atom cluster is accelerated to 30 keV, then the energy per atom will be 15 eV (See figure 3).

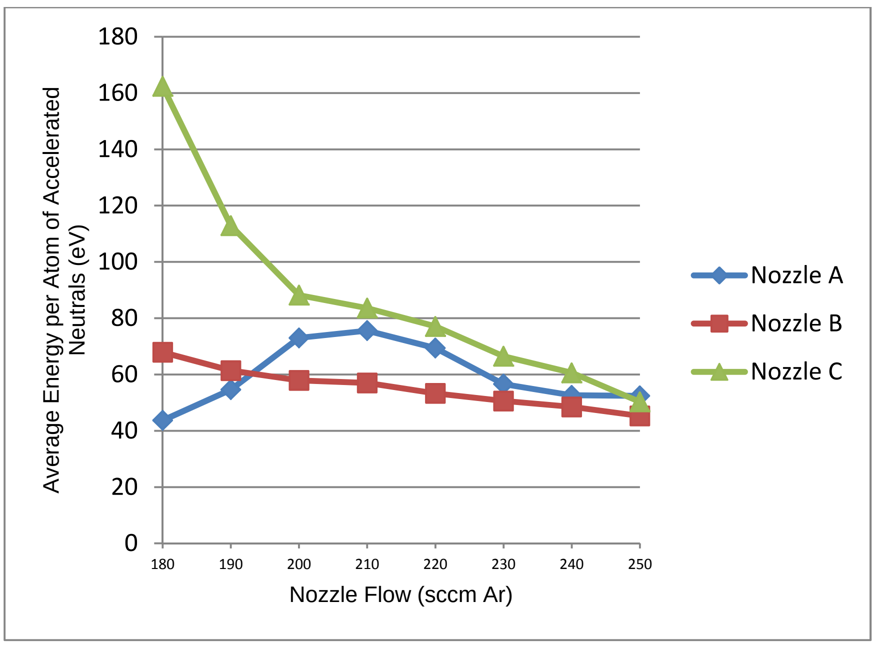

Figure 3. ANAB average energy vs. flow

The second method for controlling average ANAB atom energy is to vary the accelerating field voltage (see figure 4). As can be seen from figures 4 and 5, the third approach to controlling average energy is by varying the nozzle shape and dimensions.

Typical ANAB fluxes range up to 1E17 atoms per cm^2 per second in beams approximately 1 cm in diameter. For many applications argon gas is used, but any gaseous species can be used alone or combined with argon.

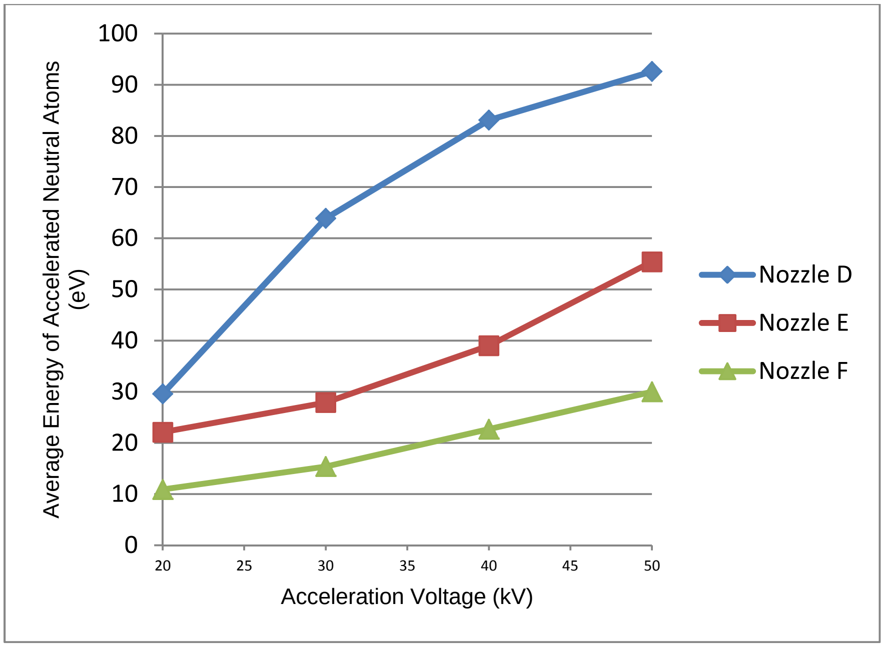

Figure 4. ANAB energy vs. acceleration voltage

III. CONCLUSION

ANAB technology can provide enabling processing capabilities for next generation device manufacturing due to its truly neutral nature. Traditional charged particle technologies attempt to provide neutral surface processing by addition of a charge compensating electron flux. However, even a neutralized process flux cannot match the performance and simplicity of the accelerated neutral atom beam (ANAB) for many applications. ANAB provides highly controllable nano-scale depth surface modifications while simultaneously offering truly charge free processing capability. It is believed that this combination of desirable properties can be used to satisfy next generation etch applications with extremely stringent demands such as those required for high aspect ratio etch of 3D surface features.

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