Optimization of Ion Beam Etch Sidewall Angle in Mo and Cr Films

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We studied the effect of performing a two-angle Ion Beam etch process in shaping the sidewall profiles of patterned Mo and Cr films. Cross-sectional SEM is used to study both the sidewall angle and the effects of redeposition on the sidewall shape. By etching first at 45° and then 5°, favorable sidewall profiles for further processing and conformal coverage are produced. We find that a total high-angle etch time of 30-40% produces sidewall angles near 80° with minimal trenching in both single edges and in 70 nm width, 200 nm period, 45 nm thick line features.

1. Introduction

Ion beam etching (IBE) has become a preferred technique for patterning multilayer devices such as giant magnetoresistance (GMR) and tunnel magnetoresistance (TMR) sensors. In this technique a collimated beam of ions is directed to a substrate, providing a physical etching mechanism that is non-selective and anisotropic to all materials in the film stack. This allows for the control of a highly vertical sidewall profile across the whole multilayer. Control of the sidewall profile is critical in defining the dimensions of the device for further processing as well as the magnetic properties of the end product.

While the IBE technique provides a means to accomplish high sidewall angles, the etch process may be optimized to obtain the desired profile. Both the physical ion beam characteristics and the etch geometry can be used to tailor the resulting sidewall. For example, adjusting the stage angle relative to the incident beam has a large impact on the resulting sidewall shape. Performing an etch with the substrate at normal incidence (0°) to the ion beam can result in a trenching effect, where a trench is etched at the bottom of the sidewall, as well as a redepositing (or "fencing") effect, where the relatively low etch rate at the sidewall results in material being deposited along the sidewall, creating extra features. Additionally, an etch at a high angle from normal incidence may result in a "foot", where a long, low-angle feature extends out from the bottom of the sidewall [1].

In this study we apply a two-angle approach for the etching of metal films masked by photoresist. The sidewall angle of Mo and Cr films are etched first at a high angle to prevent redeposition and trenching, followed by a low angle etch to prevent the formation of a large foot. Each angle's etch time is studied for its effect on the sidewall angle. The results provide guidelines on the development of multi-angle etch processes for highly vertical and uniform sidewalls.

2. Experimental

Samples of Mo films were prepared via biased target deposition (BTD) on Si substrates. Films were deposited to a thickness of 120 nm and masked with S1813 photoresist spin-coated to a thickness of 1.2 µm. The photoresist was patterned into wide line features to study the sidewalls of well-separated edges. For Cr films, 60-70 nm wide lines at a period of 200 nm were patterned with a 100-120 nm thick PHS polymer resist [2].

The IBE process was carried out using a KRI 22 cm Mo-gridded high-uniformity micro-dished two-grid ion source in a vacuum chamber with base pressure of 5×10^{-8} Torr. The substrate stage is spun at 40 rpm and offers continuous angle control ±90° from normal incidence with the ion beam. The ion source is operated at a beam voltage, V_b, of 300 V, a beam current, I_b, of 115 mA, and an accelerator voltage, V_a, of 36 V with an Ar gas supply of 20 sccm. The beam is neutralized with a plasma bridge neutralizer (PBN) operated at 1.2 A and an Ar gas supply of 10 sccm. Etching rates are characterized via stylus profilometry on separate samples.

To characterize the sidewall profiles, cross-sectional SEM was performed using a Zeiss NVision 40 Cross Beam Microscope [3].

3. Results Discussion

Fig. 1 illustrates the change in Mo etch rate as the stage angle is varied during etching. The etch rates are used to calibrate the etch times at each angle.

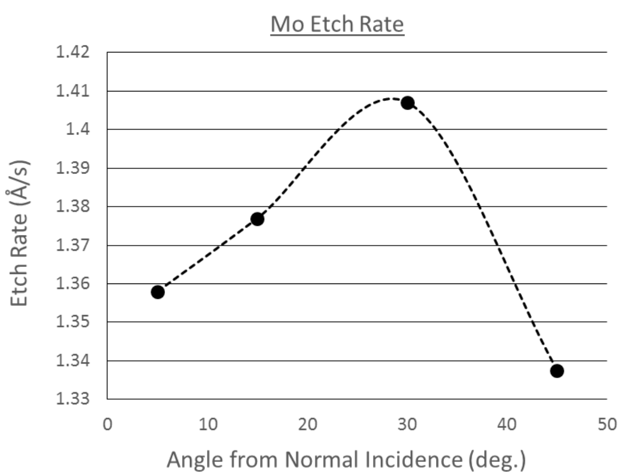

Fig. 1. Etch rate of Mo films versus stage angle with V_b = 300 V, I_b = 115 mA, and V_a = 36 V.

For the two-angle etches, a high angle of 45° is chosen for the initial etch, and an angle just off normal, 5°, is chosen as the low angle to prevent excess trenching and redeposition. Each angle has relatively similar etch rates of 1.358 Å/s at 5° and 1.338 Å/s at 45°.

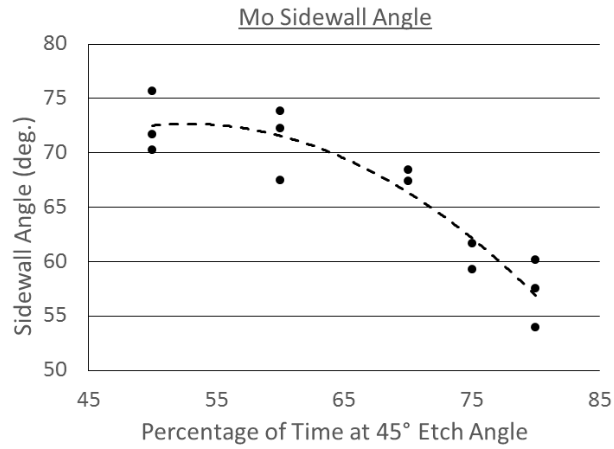

Fig. 2. Mo IBE sidewall angle as a function of etching time spent at an initial angle of 45°. The remainder of the etch is carried at 5°.

The sidewall angle is therefore characterized as a function of the percentage of time spent at the high angle of 45°. Fig. 2 presents the sidewall measurements made on multiple Mo samples at each stage angle. There is a clear trend to higher sidewall angles as more time is spent etching at the low angle.

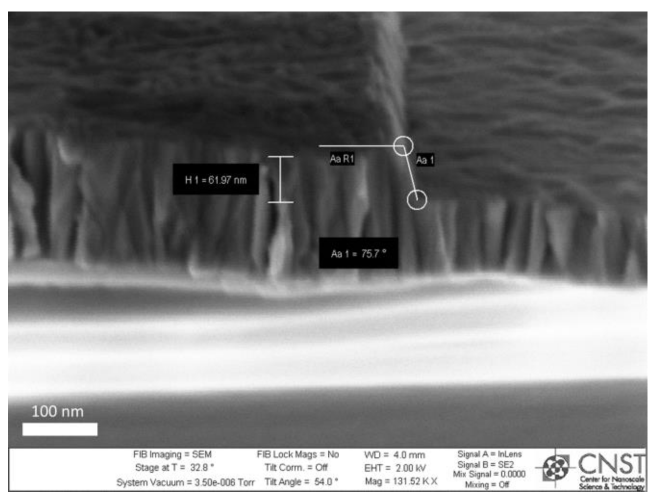

Fig. 3. Mo sidewall angle after etching 50% at 45° and 50% at 5°.

This is consistent with the collimated nature of the ion beam providing a directed etch close to normal as well as the elimination of a low-angle foot by finishing the etch at this angle. Fig. 3 shows a Mo etch completed at 50% of the etch time at 45° showing no foot or redeposition features with a relatively high sidewall angle. Improvement in the sidewall angle is expected when decreasing the 45° etch time further.

This experiment was then extended to high aspect ratio lines in Cr films. Fig. 4 shows the measured sidewall angles when decreasing the etch time at 45° to 30%. The increase in sidewall angle follows the same trend as Mo. A cross-sectional SEM is shown in Fig. 5 and again displays straight sidewalls with no redeposition features with greater than 80° sidewall angles. Fig. 5 shows a slight over-etch with some evidence of trenching due to the increased time at near-normal incidence.

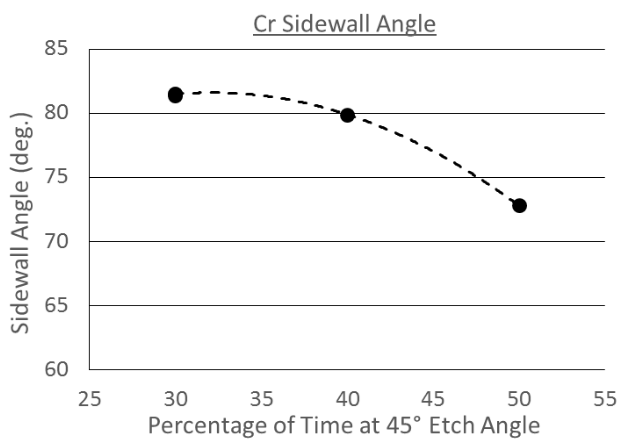

Fig. 4. Cr IBE sidewall angle as a function of etching time spent at an initial angle of 45°.

4. Conclusion

A two-angle approach was taken in order to optimize both the shape and the sidewall angle of Mo and Cr films. An initial high etch angle of 45° was performed to eliminate redeposition effects and the etch was completed at a low angle of 5° to promote high sidewall angles. The sidewall angle was found to increase when decreasing the time spent at the high angle. The sidewall profiles were found to be compatible with further processing and conformal coverage. Optimization of the sidewall angle and shape may be increased further by studying effects due to different angles and alternating between high and low angles for multiple angle etches.

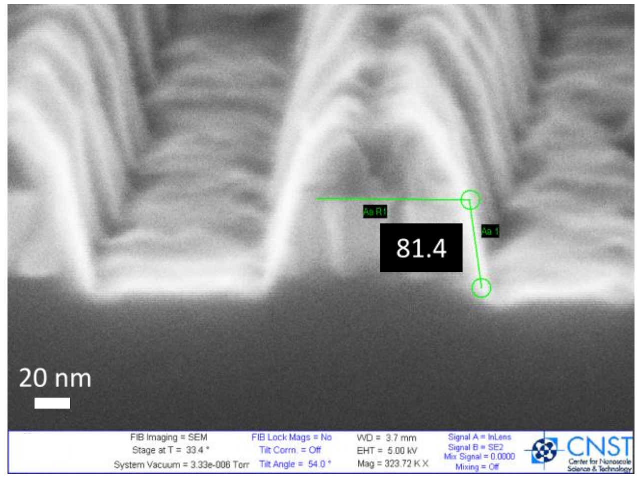

Fig. 5. Cr sidewall angle of 81.4° after etching 30% time at 45°. A thin layer of photoresist remains above Cr material.

5. References

[1] K.G. Jung, H. Cho, and S.J. Pearton. Handbook of Advanced Plasma Processing Technologies, 2000, p 607.

[2] Samples provided by Chengdu Institute of Optics and Electronics.

[3] Lithography and imaging performed at the Center for Nanoscale Science and Technology at NIST, Gaithersburg, MD.