Electrostatic Reduction of Particulates for Laser Resistant Hafnia Coatings

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Electrostatic Reduction of Particulates for Laser Resistant Hafnia Coatings

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ABSTRACT

We have reduced by 50% particulate defect density of hafnia coatings deposited onto silicon substrates through the use of electric fields, physical barriers and deposition rate. In an effort to reduce the number of hafnia (HfO_2) particulates deposited onto silicon wafers, parallel plate electrodes were placed on either side of the evaporant plume. The particulate level was determined as the deposition rate was varied from 0.75 Å/sec to 12 Å/sec. Then, parallel plate electrodes were placed on either side of the plume as a way of electrostatically deflecting hafnia particulates away from the substrates. Later a single plate electrode was used in conjunction with a physical barrier placed over the hearth. The results of our study indicate that minimal defects occur when a parallel plate electric field is applied in conjunction with a fast deposition rate. Using a screen as a physical barrier, and/or a single electrode had little or no effect. This data may be useful in the manufacture of multilayer optical coatings with high laser damage thresholds.

1. INTRODUCTION

Particulate reduction in thin film deposition systems has long been of interest to researchers searching for higher quality, higher damage threshold coatings. This is especially true with recent advances in high power laser applications. Guenther¹ has suggested a direct correlation between the number of particulates and the failure rate of a high reflector (HR) coating. It has been argued that the laser conditioning process, the procedure to enhance the laser damage threshold of coatings, could well originate from one or more of these particulates.²

Many schemes for particulate reduction have been devised. Tatsumi et. al.³ used a high voltage (-6 kV) tantalum electrode to electrostatically deflect silicon particulates away from the substrate in an electron beam system. Their results show a complete elimination of particulates (from 35/cm² to zero /cm²) at this voltage. They suggest that the larger, slower moving particulates pick up an electric charge and after doing so, are deflected away from the substrate onto the side of the chamber. Venkatesan et. al.⁴ used a high speed velocity filter (3,000 rpm) to deflect slower moving oxide particulates before they could reach the substrate while Letts et. al.⁵ found controlling power, gas flow, and pressure during the entire deposition process though feedback control drastically improved their coatings by a plasma process.

All of the referenced data shows some level of particulate reduction. Little work has been done, however, on particulate reduction of oxides deposited using an electron beam evaporation system. Since most high laser damage threshold HRs are produced by evaporating HfO_2 (hafnia) onto substrates using an e-beam system, we have chosen to investigate the reduction of hafnia particulates in an e-beam system.

2. REDUCTION OF PARTICULATES IN HAFNIA COATINGS

Using the concepts that particulates are slower moving, more likely to be charged, and physically larger than their atomic counterparts, we have attempted to configure our deposition system in such a way as to minimize the number of particulates deposited onto a substrate.

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A series of four experiments was carried out in an attempt to reduce the number of particulates in HfO_2 coatings. First, a single deflection electrode was used to try to deflect away the charged particulates. When this produced a null results, a dual-electrode system was used. This was followed by a rate study. Then we concluded with the integration of both rate and dual electrode configuration.

All work was done in a 70 cm x 70 cm x 90 cm (l x w x h) chamber with a conventional Sloan Electron Beam evaporator and a liquid- N_2 cyropanel diffusion pump. An oxygen back flow of 5 scc/min was maintained at all times. The wafer was planetated about the chamber during the runs. Base pressure was in the 10^{-7} Torr decade while run pressure was in the 10^{-4} Torr decade.

2.1 Single Electrode Study

Following the work of Tatsumi et. al. a Si wafer was placed 50 cm from the HfO_2 source. The distance from the HfO_2 source to the single Ta deflection electrode was 6 cm. High voltage could be applied to the deflection electrode using a high voltage DC power supply. A voltage of 0 to -5 kV was applied to the deflection electrode. This produced an electric field strength of about $4\text{--}6 \times 10^4$ kV/m². The hafnia films were deposited on a 3" Si test wafers. A thin (7000 Å) HfO_2 layer was deposited on the wafer at a rate of 7 Å/sec and ambient temperature. (Temperature typically went from 25°C to 90°C during the course of a run.) The acceleration voltage of the electron beam evaporator was 6 kV and the emission current was about 200 mA. Hafnia particulates were counted using an optical microscope and appear as black specs on an otherwise yellow surface.

The results of the single-electrode experiment (FIG. 1) show that within experimental error the electric field had no effect in reducing the number of HfO_2 particulates deposited onto the wafer.

FIG. 1. Null results of particle reduction using a single deflection electrode.

2.2 Double Electrode Study

Following the null results of the single-electrode experiment, we attempted to increase the electric field strength within the plume area. This was accomplished by placing a positively charged stainless steel screen on the opposite side of the hearth from the Ta deflection electrode (FIG. 2). The positive bias was

varied from 0 to +3 kV while the negative bias was varied from 0 to - 5 kV. All other factors were held constant with respect to the single electrode experiment.

FIG. 2. Schematic view of the dual electrodes for particle reduction.

Results of this dual-electrode setup are shown in FIG. 3. The increase in field strength had an effect on particulate reduction.

FIG. 3 Particulates vs. total applied voltage. Total voltage is defined as the net voltage across both electrodes.

2.3 Rate Study

In this study, deposition rate was varied from 2 Å/sec to 12 Å/sec as determined by a rate monitor and verified using a contact profilometer. The increase in rate was accomplished by increasing the emission current while keeping the electron acceleration voltage constant at 6 kV. All other parameters were kept constant with respect to the procedures outlined in Sections 2.1 and 2.2 of this paper. No voltage was applied to either electrode.

The results of this study are shown in FIG. 4. Clearly an inverse relationship between deposition rate and the number of particulates deposited on the Si wafer exists. At this time, however, no investigation into the quality or composition of the HfO_2 films deposited at their corresponding rates has been undertaken.

Particulates vs. Deposition Rate

FIG. 4. Particulates vs. Deposition rate for a Hafnia coating.

2.4 Combined dual electrode, high evaporation rate study

Finally, in an attempt to combine the benefits of both a dual electrode system and a high evaporation rate, the positively charged stainless steel screen was placed horizontally over the hearth and biased from +1 to +3 kV, while the Ta deflection electrode was again biased from 0 to -5 kV.

The purpose of the horizontal screen was twofold. First, the lines of electrostatic force remain directed across the plume, rather than diverging out into the vacuum chamber from the Ta electrode as in the single-electrode study. Second, because it acts as a physical mass filter, we can increase the evaporation rate at the source while still sustaining a low deposition rate (high oxygen/effluent impingement ratio) at the substrate. Results shown in FIG. 5 exhibit the particulate reduction trend also seen in FIG. 3 and FIG. 4.

FIG. 5 Particulates vs. Total electrode voltage. This series run with a high evaporation rate through a horizontal electrode. Deposition rate = 2-4 Å/sec.

3. Conclusion

Through the manipulation of electrostatic fields and deposition rate, we have been able to reduce the number of HfO_2 particulates by over 50%. We determined that the oxide particulates do not respond to a single electrode generated electrostatic field. The particulates do respond, however, to a dual electrode generated field if the positive electrode is placed close to the source. Perhaps the more electrostatically intense field makes it more likely that the larger, slower moving particles will contact an electron and become charged. After becoming charged, the particulate would be swept away by electrostatic attraction/repulsion.

Deposition rate has a large effect on the number of particulates deposited on the substrate. As the evaporation rate increases, the number of particulates decreases markedly. It is possible that the high energy required to produce these high deposition rates may also result in more atomic metal and less atomic oxide being deposited onto the wafer. This would adversely affect the quality of the HR.

A dual electrode system, with a positively biased screen placed horizontally over the source allows for both an increase in evaporation rate and an increase in the electrostatic fields of force. Using this apparatus, we have been able to reduce the number of particulates from $60/\text{cm}^2$ to $25/\text{cm}^2$, a decrease of 40%.

4. Further work

Investigation into the quality and characteristics of a HfO_2 layer deposited at high deposition rates (12 Å/sec) need to be undertaken. If this proves promising, then a $\text{HfO}_2/\text{SiO}_2$ multilayer should be manufactured and damage tested.

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