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High Insulating SiO_2 Thin Film Growth under VUV Irradiation

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Introduction

Silicon industry is now paying attention to high-k and SiON dielectric materials as a candidate gate insulator beyond ultra-thin (<1nm) SiO_2 film. The present limitations in ultra-thin SiO_2 film are, however, defects in the Si-O interface which is a source of leakage current. In order to improve insulating performance, sub-oxide layer in the interface must be minimized in thickness.

Our approach is to densify the SiO_2 film to minimize defect density. There are several polymorphous for SiO_2 with different packing (density); *i.e.* stishovite (4.35g/cm^3), coesite (2.93g/cm^3), quartz (2.6 ~ 2.65g/cm^3), tridymite (2.28 ~ 2.33g/cm^3) and cristobalite (2.32g/cm^3). High density SiO_2 in an amorphous form is also known; *i.e.* lechatelierite (2.5 ~ 2.65g/cm^3). Densification of glassy silica is achieved by high pressure. Density of thermally oxidized SiO_2 film on the silicon wafer is 2.14 ~ 2.23g/cm^3.[1] High density forms are expected to have less defects; *e.g* oxygen imperfection. Recently, we reported that ultra-thin SiO_2 film prepared by VUV oxidation has superior insulating performance and here we report the study using synchrotron radiation as VUV source.

We focused attention on VUV (vacuum ultraviolet) assisted oxidation which is one of low damage method for depositing highly density of SiO_2 film. The first experimentation of highly density of SiO_2 film was deposited by excimer lamps whose wavelength was 126, 172 and 222nm, in atmosphere oxygen gas. The growth of SiO_2 using these wavelength values formed ultra-thin SiO_2 films with density higher than those of conventional thermal oxidation technique. Chemical analysis by XPS (x-ray photoelectron spectroscopy) confirmed that the SiO_2 films have only small amount of sub-oxide layer.

The insulating performance of SiO_2 prepared by VUV oxidation is summarized in the following; critical breakdown voltage at 126nm oxidation is higher while leakage current is lower than those of thermally oxidized films.[2] Highly insulating SiO_2 film can be grown by VUV assisted oxidation up to 5 nm thickness.

Mechanism of VUV oxidation is still unclear but the possible mechanism through radical oxygen is proposed. However, it is difficult to describe the observation that SiO_2 is grown by 126nm radiation by such a mechanism considering strong absorption and collisions with oxygen molecules in atmospheric pressure.

Result and Discussion

The samples tidied were deposited on Si(001) standard wafer after chemical treatment. Density profiles of the SiO_2 films were obtained by grazing incidence x-ray reflectometry (GIXR). Figure 1 shows depth profile of SiO_2 using 126nm excitation at BL-20A. For comparison, the results of SiO_2 grown by thermal oxidation (Nagai *et al*) is referred. The VUV oxidation was performed for 10 hours and substrate was heated to 350°C. The SiO_2 density and thickness is ~2.3g/cm^3 and 1.4nm, respectively. When substrate temperature is lower or higher, the density decreases. The deposition rate seems to depend on photon flux and we are now trying to calibrate the photon flux.

It is found that the high density SiO_2 can be grown by 126nm irradiation using synchrotron radiation. Highly monochromatic beam will allow us to study the wavelength dependence.

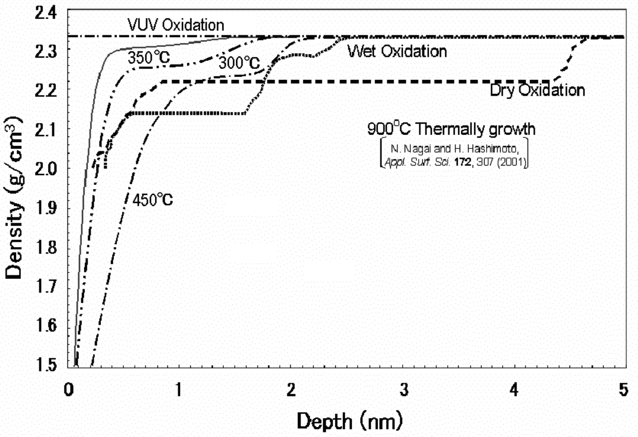

Fig. 1, The depth alternation of the density from GIXR for 126nm at VUV-SR. The growth condition of substrate temperature is 300, 350, and 450°C and 10 hour. The condition of growth chamber is kept atmosphere and flowed fresh O_2 gas. The wet and dry thermally oxidation data are referred by Nagai and Hashimoto.

References

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