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Evaluation of Interface SiO_x Transition Layer by Oscillatory Tunneling Current-Voltage Characteristics in Photo-CVD SiO_2-Si Diode

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1. Introduction

Recently, ultra-large scale integrated circuit (ULSI) has been developed extensively, so reducing the size of one element. MOS transistor, which is a key device of ULSI, affects the whole device performance and reliability greatly [1]. Basic characteristics of the MOS transistor are influenced much by quality of gate oxide and interface with Si. However, SiO_2 film formed by conventional thermal oxidation reveals some problems such as roughness of Si/SiO_2 interface and interface suboxide (SiO_x) transition layer. Then, we have deposited SiO_2 thin film on atomically flat Si at low temperature (300°C) by photo-induced chemical vapor deposition (photo-CVD) [2] and investigated their electrical characteristics.

In this work, we have studied some electrical properties of ultra thin SiO_2 film (4-10nm), discussed resonant tunneling of electron through the SiO_2 film and characterized the transition layer near the interface from the tunneling current.

2. Experimental results and discussion

P-type CZ Si (100) wafers were cleaned by RCA method. SiO_2 thin films of 4-10nm thickness were deposited on those Si substrates at low temperature (300°C) by photo-CVD using Si_2H_6 and O_2 source gases under irradiation of vacuum ultraviolet (VUV) light from a D_2 lamp. Al gate electrodes of area 0.1mm^2 were formed on the SiO_2 film by vacuum evaporation to make MOS structures.

I-V and C-V characterization

Fig.1 shows I-V characteristics of MOS diodes of photo-CVD and thermally grown SiO_2 thin films of thickness 4.5nm. Thermally grown SiO_2 film has good insulating characteristic at low electric field, and Fowler-Nordheim (FN) tunneling current flows at high electric field. In the case of photo-CVD SiO_2 film, large leakage current was observed in low electric field region. It is considered that photo-CVD SiO_2 film contains some electrical-weak spots , and the current leaks through the weak spots. The density of fixed charge of photo-CVD SiO_2 film was estimated at 1.9×10^{11}/cm^2 by high frequency C-V measurement.

UV/O_2 anneal effect

To improve the film quality, photo-CVD SiO_2 films were annealed in O_2 under ultraviolet (UV) light (D_2 lamp) for 120min at 300°C. O_2 gas exited highly by UV absorption enhances oxidation and oxygen-deficient defects are reduced effectively. Fig. 2 shows the dielectric breakdown field histogram of the photo-CVD SiO_2 films before and after the UV/O_2 annealing. The breakdown field is defined as the filed at which the diode current of 1×10^{-2}A/cm^2 flows. A and B mode failures in the breakdown are observed in as-deposited film, as shown in Fig. 2(a). However, as result of UV/O_2 annealing, dielectric breakdown characteristic is improved and becomes equivalent to the thermally grown oxide. A and B mode failures could be reduced and C mode failure occurs mainly, as shown in Fig. 2(b). I-V characteristic of the annealed SiO_2/Si is quite similar to that of thermally grown SiO_2/Si as shown with closed circles in Fig. 1. It is considered that as-deposited photo-CVD SiO_2 has only weak network, but UV/O_2 annealing could make these weak bonds strong.

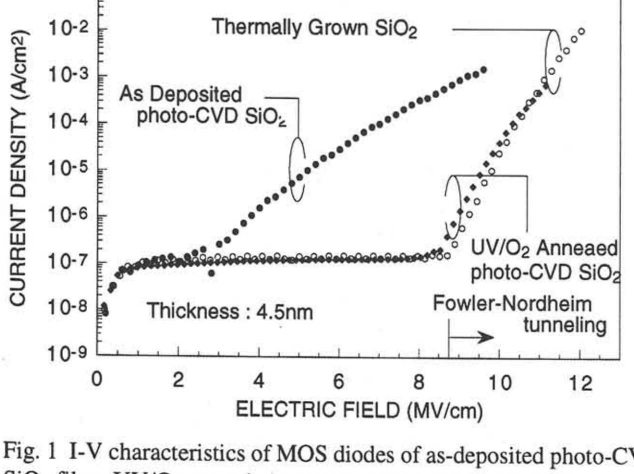

Fig. 1 I-V characteristics of MOS diodes of as-deposited photo-CVD SiO_2 film , UV/O_2 annealed one and thermally grown one.

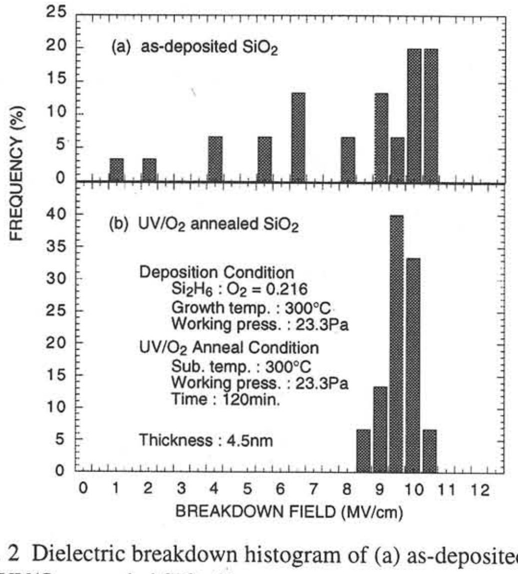

Fig. 2 Dielectric breakdown histogram of (a) as-deposited SiO_2 and (b) UV/O_2 annealed SiO_2 films.

Oscillatory FN tunneling current

FN tunneling current in ultra thin SiO_2 film is expected to behave oscillatory at low field as tunneling electron is reflected by SiO_2/Si interface[3]. So the tunneling current through SiO_2 has been analized theoretically. The transmission probability D for one electron FN tunneling through a trapezoïdal barrier is given

$$D = b\exp\left(\int_0^{\phi_m + E'} \kappa(\varepsilon) d\varepsilon / eF\right), \qquad (1)$$

where F is electric field in the oxide and ϕ_m is barrier height. b shows the modulating factor and this modulating effect can be detected only in very thin oxides. The expression for b is obtained as

$$b = (\alpha k_s/\pi) \Big/ \left\{\left[k_s Ai(-\alpha x_1)\right]^2 + \left[\alpha Ai'(-\alpha x_1)\right]^2\right\}, \qquad (2)$$

where Ai and Ai' are the Airy function and its derivative respectively and x_1 is the distance from the interface at which the electron emerges to conduction band of SiO_2 at energy E'. Oscillation of FN tunneling current was simulated using eq. (1) and (2). Fig. 3 shows the calculated result where J_0 is the current without reflection at the interface (case of thick oxide). As the thinner interface transition layer, the clearer oscillation can be observed.

We measured FN tunneling current at low temperature (100K). Fig. 4 shows FN tunneling current characteristics of as-deposited photo-CVD SiO_2 film and thermally grown SiO_2 film of thickness 4.7nm. Fig.5 shows oscillation component of these characteristics. Oscillation of photo-CVD SiO_2 film is much clearer than that of the thermally grown SiO_2 film. So, it is considered that interface transition layer of photo-CVD SiO_2 film is thinner than that of thermally grown SiO_2 film as SiO_2 film is grown at low temperature and SiO_2 are deposited without unsatisfactory SiO_x ($0<x<2$) formation. Therefore, photo-CVD method could form abrupt interface.

3. Conclusions

Electrical characterization of SiO_2 thin film deposited by photo-CVD method at 300°C has been carried out. As the result of I-V measurement, leakage current was observed low electric field region, and as-deposited photo-CVD SiO_2 film contained some electrical-weak spots. However, UV/O_2 annealing could reduce the leakage current, and dielectric breakdown characteristic is improved to be equivalent to thermally grown oxide. Current-voltage characteristics show oscillatory dependence and are considered to be dependent to interface transition layer. Interface transition layer of photo-CVD SiO_2 film is thinner than thermally grown SiO_2 film from the comparison of the oscillation intensity of the FN tunneling current. Oscillatory current is one of good characterizing methods to evaluate the SiO_x transition layer.

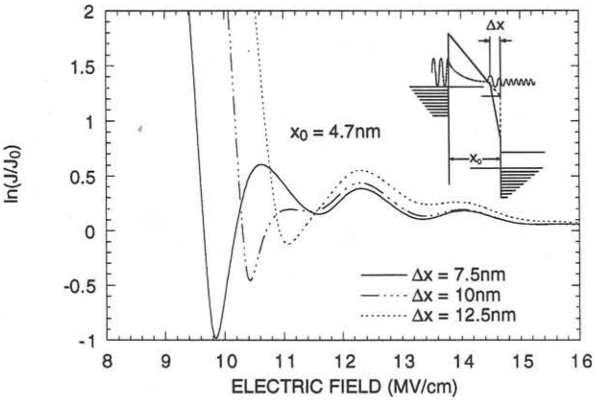

Fig. 3 Simulation of the oscillatory component ratio of FN tunneling current with and without electron reflection at interface.

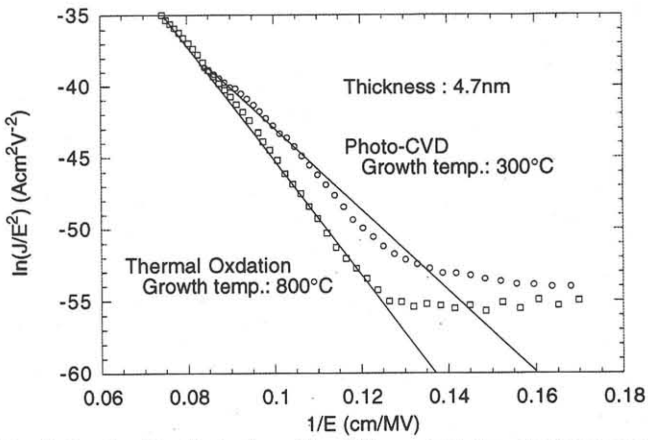

Fig. 4 Fowler-Nordheim tunneling J/E_2 vs. 1/E characteristics measured for photo-CVD SiO_2 film and thermally grown SiO_2 film. Straight lines shown current without reflection at the interface.

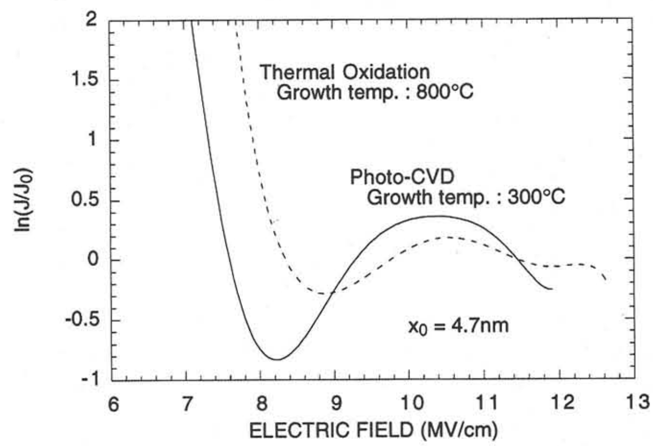

Fig. 5 Oscillatory component ratio of measured FN tunneling current without electron reflection at interface.

4. Acknowledgments

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5. References

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