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J-3-4 Electric characteristics of Si_3N_4 films formed by directly radical nitridation on Si (110) and Si (100) surfaces.

Masaaki Higuchi[1], Takashi Aratani[1], Tatsufumi Hamada[1], Akinobu Teramoto[2], Takeo Hattori[2,3], Shigetoshi Sugawa[1]
Tadahiro Ohmi[2], Seiji Shinagawa[3], Hiroshi Nohira[3] Eiji Ikenaga[4], Keisuke Kobayashi[4],
PHONE: +81-22-795-3977, FAX: +81-22-795-3986, E-mail: higuchi@fff.niche.tohoku.ac.jp
[1]Graduate School of Engineering, Tohoku University,
6-6-10 Aza-Aoba, Aramaki, Aoba-ku, Sendai 980-8579, JAPAN
[2]The New Industry Creation Hatchery Center (NICHe), Tohoku University, [3]Musashi Institute of Technology, [4]JASRI/SPring8

Introduction

The reducing of a gate leakage current and the improvement of current drivability of MOSFET are very important for realizing the high performance MOS circuits. It has been reported that the Si_3N_4 formed by direct radical nitridation of Si has been low leakage current density and high reliability [1-3]. It has been also reported that the current drivability of MOSFET has been improved by using Si (110) surface [4-5] and 3D structured device [6]. We considered that MOSFET could be higher performance by combined using of Si (110) and Si_3N_4 gate insulator formed by direct radical nitridation of Si.

In this paper, we demonstrate the low gate leakage current, no hysteresis and low interface states density of Metal Nitride Silicon Capacitor (MNSCAP) with Si_3N_4 film formed on Si (110). We study the dependence of interface transition region of Si_3N_4 films on Si surface orientation, and demonstrate that the interface transition region of Si_3N_4 films formed on high Si atom density surface as Si (110) surface becomes narrow.

Experimental

MNS capacitors were fabricated on Cz n-type (100) and (110) silicon substrate with phosphorous concentrations of 5×10^{15}cm^{-2}. Surface micro-roughness of Si (100) and Si(110) surfaces is suppressed by a wet oxidation and maintained by using 5-step room temperature cleaning [5]. Si_3N_4 films were formed by radical NH produced in the microwave excited high-density Xe/NH_3 mixture gases plasma at a pressure of 20 Pa and 600°C. The microwave frequency and power were 2.45GHz and 5W/cm^2, respectively.

For investigating the chemical structure Si_3N_4/Si interface, the 1050 eV photons' excited Si 2*p* photoelectron spectra arising from Si_3N_4/Si interface were measured with energy resolution of 100 meV for photoelectron at high brilliant soft-x-ray undulator beam line (BL27SU) of Super Photon Ring 8 GeV (SPring-8).

Results and Discussion

Fig.1 shows the J-V curves of MNS capacitors having Si_3N_4 films formed on Si (100) surface and Si (110) surface. The gate current of Si_3N_4 films formed on Si (110) surface is the same as that formed on Si (100) surface. Fig.2 shows the gate current density (Jg) as a function of EOT. The gate current of Si_3N_4 films formed on Si (110) surface reduces 3 orders of magnitude compared with conventional SiO_2 films. Fig.3 shows the C-V curves of MNS capacitors having Si_3N_4 films formed on Si (100) surface and Si (110) surface. There are no hysteresis existing for both capacitors. Fig.4 shows the interface states density of MIS capacitor formed on Si (100) and Si (110) as determined by Quasi-static C-V measurement. Interface is formed by direct nitridation of 1.8nm-Si_3N_4 on silicon surfaces. Following CVD-oxide (27nm) deposition are done for suppressing of leakage current. The interface states density at midgap of MIS capacitor formed on Si (100) and Si (110) are less than 6×10^{10} eV^{-1}cm^{-2} and less than 5×10^{10} eV^{-1}cm^{-2}, respectively. These results and no hysteresis indicate that Si_3N_4 films formed on Si (110) surface have excellent interface characteristics. Fig. 5 shows Si $2p_{3/2}$ photoelectron spectra arising from Si_3N_4/Si structure of Si_3N_4 films that formed on Si (100), Si (111) and Si (110) surface with photoelectron take-off angle 52°. The chemical shift and full width at half maximum (FWHM) for Si $2p_{3/2}$ spectra originated in intermediate nitridation states (Si^{n+}) and amount of intermediate nitridation states density in the Si_3N_4 films on Si (100), Si (111) and Si (110) surfaces are summarized in table I. Fig.6 shows the dependence of intermediate nitridation states density of Si_3N_4 films formed on Si (100), Si (111) and Si (110) on 1/ (Si area density). Intermediate nitridation states density becomes smaller, as Si area density becomes larger. These results indicate that the transition region of Si_3N_4/Si interface decreases with an increase of the Si atom density surface such as Si (110) surface. It has been reported that the interface states density in MOS device has been related to the quantities of interface transition region [7]. We consider that the Si_3N_4 gate insulator formed on Si (110) have the high quality interface characteristics for low intermediate nitridation states density.

Conclusion

We succeeded in forming of the high quality Si_3N_4 film and Si_3N_4/Si interface on Si (110) surface. The gate current reduces 3 orders of magnitude compared with conventional SiO_2 films, and no hysteresis and interface states density is less than 5×10^{10}eV^{-1}cm^{-2}. The Si_3N_4/Si interface transition region is less than 1 monolayer. This indicates that an abrupt compositional transition layer can be realized at Si_3N_4/Si interface. It is found that the intermediate nitridation states density of Si_3N_4 films becomes smaller, as Si area density becomes larger. This indicates that interface transition region of Si_3N_4 film formed on high Si atom density surface as Si (110) surface become narrow. This technology that combined the Si_3N_4 film and using of Si (110) surface is sufficient ability for the gate insulator of sub 100 nm ULSIs devices.

References

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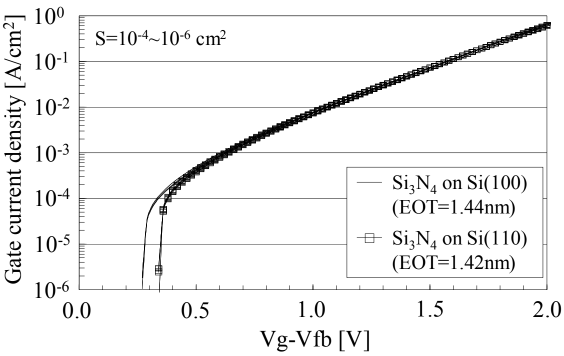

Fig.1 J-V curves of MNS capacitors having Si_3N_4 films formed on Si(100) surface and Si (110) surface. The gate current of Si_3N_4 film formed on Si(110) is equivalent to that formed on Si(100).

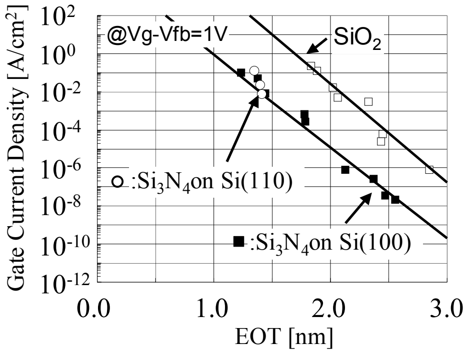

Fig.2 Gate current density comparing SiO_2 film on Si(100) and Si_3N_4 film on Si(100) and Si(110) as a function of the EOT. The gate current of Si_3N_4 film on Si(110) reduces 3 orders of magnitude compared with conventional SiO_2 films.

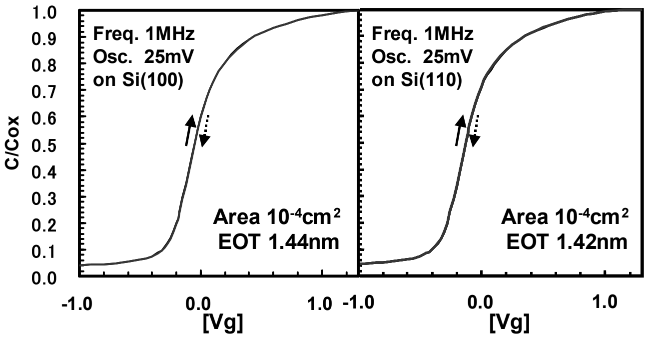

Fig.3 High-frequency C-V curve of MNS capacitor grown on Si(100) and Si(110).There is no hysteresis existing.

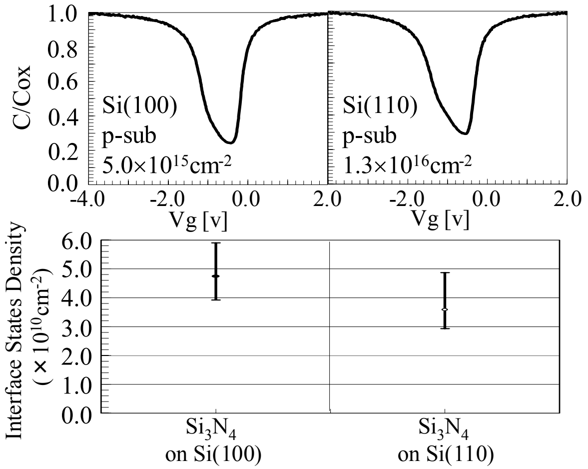

Fig.4 The interface states density of MIS capacitor formed on Si (100) and Si (110) as determined by QSCV measurement. Interface is formed by direct nitridation of 1.8nm-Si_3N_4 on silicon surface. Following CVD-oxide deposition are done for suppressing of leakage current.

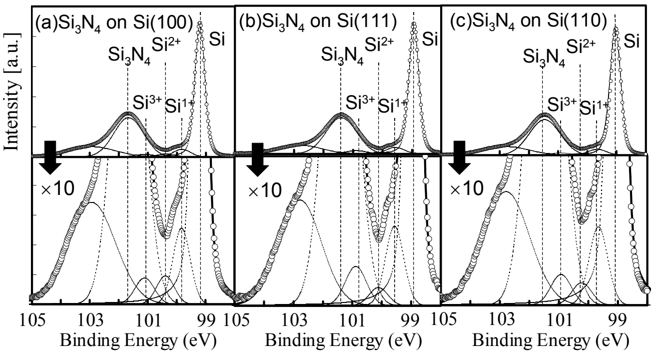

Fig.5 Si $2p_{3/2}$ photoelectron spectra measured for Si_3N_4/Si interface on Si(100), Si(111) and Si(110) with photoelectron take-off angle 52°.

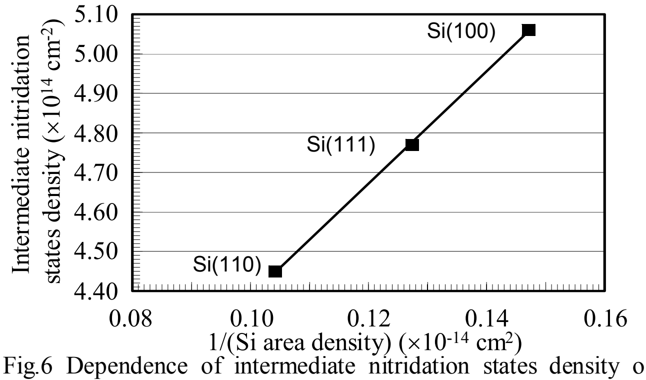

Fig.6 Dependence of intermediate nitridation states density of Si_3N_4 films formed on Si (100), Si(110) and Si(111) on Si area density. The interface transition region of Si_3N_4 film formed on high Si atom density surface as Si (110) surface becomes narrow.

TABLE I. Chemical shift and full width at half maximum (FWHM) for Si $2p_{3/2}$ spectra originated in $Si^{n+}$and amount of Si^{n+} and total amount of interface nitridation states densities for Si_3N_4 films on Si(100), Si(111) and Si(110).

	Chemical shift (eV)/FWHM (eV)			Amount of interface nitridation states density ($\times 10^{14}$atoms/cm^2)			
	Si^{1+}	Si^{2+}	Si^{3+}	Si^{1+}	Si^{2+}	Si^{3+}	Total
Si(100)	0.62 0.70	1.18 0.72	1.90 0.78	2.86	1.10	1.10	5.06
Si(111)	0.63 0.73	1.18 0.74	1.95 0.84	2.69	1.04	1.04	4.77
Si(110)	0.62 0.74	1.19 0.78	1.89 0.81	2.69	0.73	1.02	4.45