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Interface properties of 4H-SiC MOS structures studied by a slow positron beam

Masaki Maekawa[1], Atsuo Kawasuso[1], Masahito Yoshikawa[2] and Ayahiko Ichimiya[1]

[1]Advanced Science Research Center, Japan Atomic Energy Research Institute
Watanuki, 1233, Takasaki, Gunma, 370-1292, JAPAN, maekawa@taka.jaeri.go.jp

[2] Takasaki Establishment, Japan Atomic Energy Research Institute
Watanuki, 1233, Takasaki, Gunma, 370-1292, JAPAN

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Abstract. Interfacial defects existing near the SiO_2/SiC interface are an important issue for fabrication of high performance SiC devices. We investigate a thermally grown SiO_2/SiC layer of 4H-SiC MOS structure by positron annihilation spectroscopy. The Doppler broadening of annihilation quanta was measured as a function of the incident positron energy and the gate bias. Applying a negative gate bias, significant increases in *S*-parameters were observed. This indicates the migration of implanted positrons towards the SiO_2/SiC interface and annihilation at interfacial defects. Ultraviolet (UV) ray irradiation was used to extract the influence of the positron trapping to the interfacial states. *S*-parameters in the interface region were reduced by UV irradiation. This shows that positron trapping probability decreased because the charge state of interfacial defects changed to positive. From the recovery of *S*-parameters after 24 hours, the interfacial states discharge slowly and exist in large quantities, because the changes of *S*-parameter by the UV irradiation are larger than changes induced by bias change.

Introduction

Silicon carbide (SiC) is a suitable material for high-temperature, high-power and high radiation resistance devices due to its excellent intrinsic properties, for example a wide band gap, high electron mobility or high thermal conductivity [1,2]. It is attractive that an insulating SiO_2 film can be grown on SiC surfaces by thermal oxidation, thus allowing fabrication of metal-oxide -semiconductor (MOS) structures [3]. However, the density of interfacial defects and interface states in thermally grown SiO_2/SiC interfaces still remains about two orders of magnitude higher than those for SiO_2/Si interfaces [4-6]. These centers degrade the properties of SiC devices, such as the channel mobility, and hence prevent the fast operation of MOSFET. The success of SiC devices depends on the improvement of the quality of the SiO_2/SiC interface. Therefore, characterization of SiO_2/SiC interfaces is an important issue. Positron annihilation spectroscopy (PAS) is known as a tool for a detection of open volume defects in solids. Positrons are efficiently trapped by open volume defects due to their positive charge. Using a slow positron beam, depth profiling of defects near the surface region is possible. Various positron studies suggest the existence of open-volume type defects at SiO_2/Si interfaces and their passivation with some specific treatments [7-10]. In this study, we investigate the characteristics of the SiO_2/SiC interface in SiC-MOS using PAS measurements.

Experimental

MOS capacitors used in this experiment were fabricated on *n*-type 4H-SiC epilayers oriented 8^o-off the (0001) direction and purchased from CREE Research Inc. The net donor concentration of the epilayers was about $5\times10^{15}cm^{-3}$. The oxide layer was grown by pyrogenic oxidation at 1100˚C for 3h. The thickness of the oxide layer is approximately 40 nm. Aluminum films (25 nm thick) were deposited on the oxide films as gate electrodes. Backside contacts were also formed by deposition of aluminum films after removal of oxides to make ohmic contacts. Positrons were implanted into fabricated SiC-MOS structures by applying a bias voltage (V_g) though the gate electrodes. The Doppler-broadening of the annihilation quanta was measured and characterized using the *S*-parameter.

Results and Discussion

Figure 1 shows the incident energy dependence of *S*-parameters (*S-E* curve) applying various V_g for the MOS samples. At V_g=0V, constant *S*-parameter for high energies (~8 keV) is attributed to annihilation in SiC epitaxial layers. Higher *S*-parameters at 1 keV are attributed to the annihilation of the positrons in aluminum. The 1-2 keV regions where *S*-parameters begin to decrease correspond to the SiO_2 layer. Hence the regions at 2 keV< E <8 keV reflect the properties of the SiO_2/SiC interface. At V_g< 0V, *S*-parameters markedly increased. In the range of 5-10 keV, a characteristic increase (small bump) is observed at V_g = -2V. In this energy region, many positrons are implanted into the depletion layer. Probably positrons are accelerated toward the SiO_2/SiC interface by a negative electric field and get trapped by interfacial defects. *S*-parameters increase with the increase of gate bias, and in the case of V_g = -10V, the *S*-parameter saturated at almost the same value as aluminum. This indicates that positrons can pass through the SiO_2 layer, and that the probability of arrival in the aluminum layer is increasing with gate bias [11]. Namely, the observed *S*-parameter is mixture of contributions of the *S*-parameter of each layer. The changes in *S*-parameters are not simply reflected by the information on a SiO_2/SiC interface.

We attempt to extract the influences of the interfacial traps on the positrons more clearly by inducing change only to the interface by irradiation of the MOS specimen by ultraviolet (UV) rays. To irradiate the sample from the gate electrode, another MOS specimen (SiO_2:20 nm, Al:13 nm) was fabricated. The measured *S-E* curve is shown in Fig. 2. Before UV irradiation, a maximum of the *S*-parameter appeared in the range of 5-10 keV, which is attributed to a SiO_2/SiC interface. After UV irradiation, the *S*-parameter decreased and such a maximum disappeared. Electron-hole pairs are generated due to UV irradiation and the n-type MOS structure under negative gate bias is in 'inversion' i.e. *p*-type[12,13]. Therefore, the *S-E* curves after UV ray irradiation are like that of *p*-type MOS[14]. This indicates that the probability of positron trapping at the interfacial defects is decreased by a positive charge, due to the occupation of the interfacial states by holes. To demonstrate the response of the *S*-parameter to gate bias voltage and UV irradiation more in detail, *S* versus V_g curves were determined at an incident positron energy of 8 keV. Figure 3(a) and (b) show obtained *S-V* curves before and during UV irradiation. This is because the charge states of interfacial states are changed to positive, and the trapping probability of a positron was decreased. As a result, changes of *S*-parameter are small, like *p*-type MOSs. After turning off an ultraviolet ray and keeping the specimen in the dark, the response of the *S*-parameter to gate bias voltage was still small. This

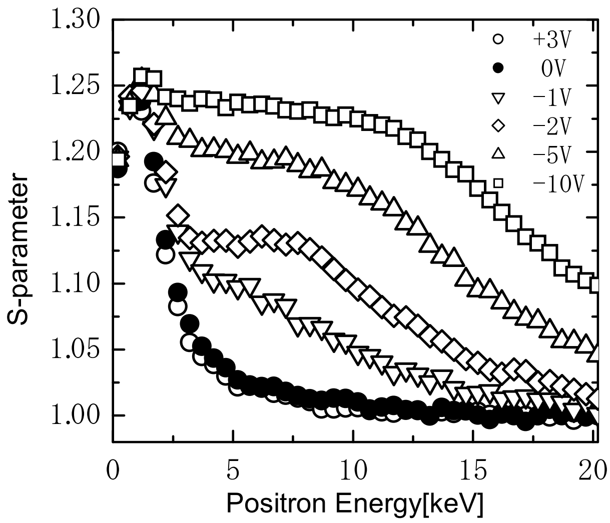

Fig. 1. *S*-parameters as a function of incident positron energy at various gate bias (V_g) for *n*-type MOS structure made by pyrogenic oxidation.

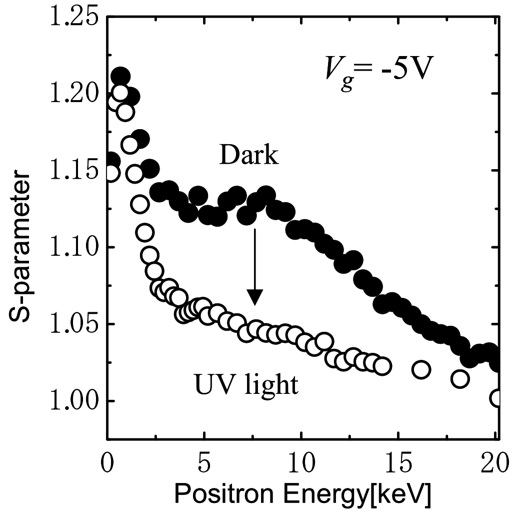

Fig. 2. *S-E* data at V_g = -5 V. After UV irradiation, S-parameter decreased.

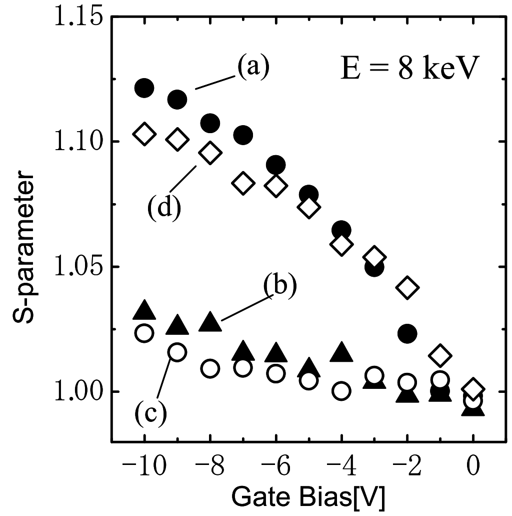

Fig. 3. *S-V* data taken at a positron energy of 8 keV. (a):before UV irradiation, (b):during UV irradiation, (c):after UV irradiation, (d): after leaving the MOS sample in open circuit for 24 hours.

shows that the charge state of interfacial states is held positive. It is suggested that the energy level of those interfacial states is quite deep, because the discharge did not occur after applying the bias voltage. However, the *S*-parameter was recovered after leaving the MOS sample in open circuit for 24 hours (Fig. 3(d)). This indicates that changes of *S*-parameter by UV irradiation reflects not a chemical irreversible change but a reversible change resulting from the difference in the positron trapping probability caused by different charge state of interfacial defects. Moreover, the interfacial defects are deep level defects that can charge and discharge comparatively slowly. Such deep level defects exist in quite large quantities because the changes of *S*-parameter by UV irradiation are larger than changes by bias change. Thus PAS measurements show the presence of interfacial defects at SiO_2/SiC interfaces.

References

[1] M. Yoshikawa, H. Itoh, Y. Morita, I. Nashiyama, S. Misawa, H. Okumura and S. Yoshida, J. Appl. Phys. 70(1991) 3.
[2] G. Harris, Properties of Silicon Carbide, The Institute of Electrical Engineers, London, 1995.
[3] H.Morkoc, S.Strite, G.B.Gao, M. E. Lin, B. Sverdlov and M. Bruns, J. Appl. Phys. 76 (1994) 1363
[4] R. Friedriches, E. P. Burte and R. Schorner, Appl. Phys. Lett. 95 (1994) 1665.
[5] R. Friedriches, E. P. Burte and R. Schorner, J. Appl. Phys. 79 (1996) 7814.
[6] D. Aloc, P. K. Mclarty and B. J. Baliga, Appl. Phys. Lett. 64(1994) 2845.
[7] V. V. Afanas'ev, M. Bassler, G. Pensl and A. Stesmans: Mater. Sci. Forum 389-393 (2002) 961.
[8] K. Fukuda, J. Senzaki, M. Kushibe, K. Kojima, R. Kosugi, S. Suzuki, S. Harada, T. Suzuki, T. Tanaka and K. Arai, Mater. Sci. Forum 389-393 (2002) 1057.
[9] J. Isoya, R. Kosugi, K. Fukuda and S. Yamasaki, Mater. Sci. Forum 389-393 (2002) 1025.
[10] K. Fukuda, S. Suzuki, J. Senzaki, R. Kosugi, K. Nagai, T. Sekigawa, H. Okushi, S. Yoshida, T. Tanaka and K. Arai, Mater. Sci. Forum 338-342 (2000) 1283.
[11] M. Clement, J. M. M. de Nijs, P. Balk, H. Schut and A. van Veen, J. Appl. Phys 81(1997) 1943.
[12] P. Asoka-Kumar, K. G. Lynn and D. O. Weich: J. Appl. Phys. 76(1994) 4935.
[13] R. Suzuki, T. Ohdaira, A. Uedono and Y. Kobayashi, Appl. Surf. Sci. 194 (2002) 89.
[14] M. Maekawa, A. Kawasuso, M. Yoshikawa and H. Itoh, Appl. Surf. Sci 216(2003) 365.

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DOI References

[7] V. V. Afanas'ev, M. Bassler, G. Pensl and A. Stesmans: Mater. Sci. Forum 389-393 (2002) 961.
10.4028/www.scientific.net/MSF.389-393.961
[8] K. Fukuda, J. Senzaki, M. Kushibe, K. Kojima, R. Kosugi, S. Suzuki, S. Harada, T. Suzuki, T. anaka and K. Arai, Mater. Sci. Forum 389-393 (2002) 1057.
10.4028/www.scientific.net/MSF.389-393.1057
[9] J. Isoya, R. Kosugi, K. Fukuda and S. Yamasaki, Mater. Sci. Forum 389-393 (2002) 1025.
10.4028/www.scientific.net/MSF.389-393.1025
[10] K. Fukuda, S. Suzuki, J. Senzaki, R. Kosugi, K. Nagai, T. Sekigawa, H. Okushi, S. Yoshida, T. anaka and K. Arai, Mater. Sci. Forum 338-342 (2000) 1283.
10.4028/www.scientific.net/MSF.338-342.1283
[13] R. Suzuki, T. Ohdaira, A. Uedono and Y. Kobayashi, Appl. Surf. Sci. 194 (2002) 89.
10.1016/S0169-4332(02)00094-6