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Radiation effects on ohmic and Schottky contacts based on 4H and 6H-SiC

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ABSTRACT

A systematic study of Ni based ohmic and Schottky contacts (SCs) onto the n-4H-SiC and n-6H-SiC under relatively low-dose ($1 \times 10^{12}\ e^{-}\ cm^{-2}$) and high-energy (6, 12, 15 MeV) electron irradiation (HEEI) has been introduced. Lower specific contact resistivity has been reached for Ni based ohmic contact structures on both 4H and 6H-SiC after each electron irradiation. This finding has been explained by the displacement damage produced by the collision of electrons with atoms of Ni contact material. It has been observed that the HEEI caused to increase in the ideality factors of both SCs indicating deviation from thermionic emission theory in current transport mechanism. While the Schottky barrier height (SBH) for Ni/4H-SiC SC remains nearly constant, an increase has been observed for the Ni/6H-SiC SC. Donor concentrations for both diodes have decreased with increasing electron energy probably due to the trapping effect of the irradiation induced defect(s).

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1. Introduction

SiC is an indirect wide band gap compound semiconductor which has many important electrical, chemical, thermal and mechanical properties such as high thermal conductivity, high breakdown field, high saturation electron drift velocity, high chemical stability and strong mechanical strength as reviewed by the authors [1,2]. Because of these excellent properties, it is preferred to use in semiconductor devices and materials which are operated in harsh environments such as radiation, high temperature, high pressure and high corrosion, etc. In order to use SiC in semiconductor device arena under these mentioned harsh environments, high quality ohmic and Schottky contact properties is required.

So far, many different metals have been used as both ohmic and SC material such as Ni, Al, Co, Ti, Au and W. In addition, because of its superior advantages such as refractory nature, producing low ohmic contact resistivity [3–11] and high SBH [12–15], Ni has been generally chosen as the contact material both for ohmic and SCs in SiC [3–16]. The effects of high-energy proton irradiation and high-dose gamma ray irradiation on 4H-SiC Schottky rectifiers have been investigated by Nigam et al. and Kim et al. respectively, [17,18]. Although both Ni ohmic and SC properties for 4H-SiC have been reported by Perez et al. [11], there is no information for the performance of Ni both for ohmic and SC for 6H-SiC and also its performance under electron irradiation has not been reported for 4H and 6H-SiC samples.

In this study, Ni based ohmic and Schottky contacts onto the 4H- and 6H-SiC were characterized in terms of their electrical parameters under high-energy (6, 12, 15 MeV) and relatively low-dose ($1 \times 10^{12}\ e^{-}\ cm^{-2}$) EI. Transmission line method (TLM) and, *I–V* and *C–V* measurements were performed before and after each irradiation for ohmic contacts and SCs, respectively. The effects of HEEI on Ni ohmic and SC parameters were discussed in detailed for both 4H- and 6H-SiC materials.

2. Experiment

Silicon carbide bulk wafers used in this study were purchased from University Wafer. Both wafers are two sides polished and have <0001> crystalline orientation. In order to ensure the sample homogeneity, four adjacent pieces with dimensions of $5 \times 5 \times 0.5\ mm^3$, two of them are the reference samples and the other two are the samples to irradiate, were cut out from both 4H and 6H-SiC wafers. All wafers were subjected to the well known Si cleaning process. 5N Ni was chosen as the ohmic and Schottky contact element because of becoming one of the most popular materials used in SiC metallization [7]. 5N Au element is used for cap layer in order to prevent the oxidation of Ni contacts. Both metals were evaporated through shadow masks

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sequentially as produced previously in our study [19], in a Univex-300 Pump system with a pressure of 4×10^{-5} Torr. In order to obtain good contact properties, ohmic contacts were annealed in a homemade furnace under dry N_2 gas flow at 950 °C for 10 min [20].

Radiation effects on the electrical parameters of the Au/Ni/n-4H-SiC and Au/Ni/n-6H-SiC ohmic contact structures were investigated by means of the TLM measurements. Before HEEI, TLM measurements were performed on these ohmic contacts. Then, both ohmic contacts were irradiated sequentially high energetic (6, 12, 15 MeV) electrons. After each irradiation step, the TLM measurements were repeated. The details of TLM measurements and a SEM image of the shadow mask used in transferring the ladder pattern to the sample surface can be found in our earlier reports [21,22]. In order to perform *I–V* and *C–V* measurements Keithley-487 picoampermeter and HP-4192 A impedance analyzer (at 50 kHz) were used, respectively.

By using the thermionic emission theory, Schottky contact parameters such as SBH, ideality factor and Fermi level energy position have been determined using the formulation given by our earlier reports [23,24].

Each Schottky contact was irradiated with high-energy (6, 12, 15 MeV) and flux of $3 \times 10^7\ e^- cm^{-2} s^{-1}$. The total dose of the all contacts were arranged to be $1 \times 10^{12}\ e^- cm^{-2}$. All irradiation experiments were carried out at room temperature for approximately 5 min. EI was made by Siemens-Primus linear electron accelerator which allows one to accelerate the electrons up to 21 MeV energy electrons. This dose of irradiation corresponds to the nearly one year period of fluence in the inner zone of the earth's trapped-electron radiation belts [25].

3. Results and discussion

3.1. Ohmic contacts; TLM measurements

Specific contact resistivity, ρ_c, of Ni contacts produced onto the 4H and 6H-SiC were calculated before the HEEI as $(17.1 \pm 7.1) \times 10^{-5}$ and $(5.4 \pm 2.89) \times 10^{-5}\ \Omega\,cm^2$, respectively. Nearly three times lower value of specific contact resistivity has been reached for 6H-SiC with respect to 4H-SiC. Table 1 shows the Ni based ohmic and SC properties obtained from the literature. A close match can be found between values obtained from the present study and the literature given in Table 1.

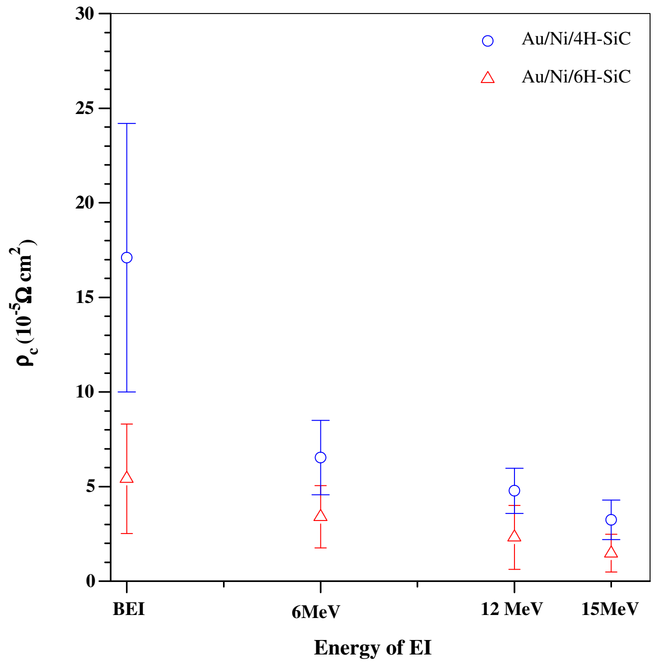

Fig. 1. The variation of ρ_c values with respect to the electron irradiation energy of the Au/Ni/n-4H-SiC and Au/Ni/n-6H-SiC ohmic contacts. The huge error bars could be resulted from the instrumentation problems.

Fig. 1 shows HEEI effects on the ρ_c of Ni based 4H and 6H-SiC ohmic structures. As can be seen from the plot, the specific contact resistivity for Au/Ni/n-4H-SiC and Au/Ni/n-6H-SiC was decreased with increasing electron energy. After the last electron irradiation of 15 MeV, almost five times decrease in ρ_c has been observed for both Au/Ni/n-4H-SiC and Au/Ni/n-6H-SiC structures. It is mostly expected that the particle irradiation gives rise to the displacement damage in semiconductor materials and devices. Therefore, this decrease in ρ_c may be resulted from the diffusion of Ni atoms into the semiconductor with the influence of collision between energetic electrons–atoms of the contact material. Furthermore, heat which emerged due to the electron–lattice interaction can cause a kind of annealing effect and thus diminishes the ohmic contact resistivity drastically.

Table 1
Literature values for the electrical parameters of Ni based ohmic and SCs onto both 4H and 6H-SiC samples.

References	Ohmic contacts		Schottky contacts			
	ρ_c (Ω cm^2)		n	ϕ_B (eV)	n	ϕ_B (eV)
	4H-SiC	6H-SiC	4H-SiC		6H-SiC	
Present study	17.1×10^{-5}	5.4×10^{-5}	1.55	0.91	1.12	0.67
La Via et al. [3]	4.8×10^{-5}	–	–	–	–	–
Pecz [4]	3.0×10^{-6}	–	–	–	–	–
Roccaforte et al. [5]	–	3.9×10^{-5}	–	–	–	–
Machác et al. [6]	–	3.8×10^{-4}	–	–	–	–
Marinova et al. [7]	–	2.8×10^{-6}	–	–	–	–
Kakanakova et al. [8]	2.8×10^{-6}	–	–	–	–	–
Saxena et al. [9]	–	8.2×10^{-5}	1.05	1.59	–	–
Yang et al. [10]	1.4×10^{-5}	–	–	–	–	–
Perez et al. [11]	3.0×10^{-5}	–	2.10	0.77	–	–
Nava et al. [12]	–	–	1.05	1.74	–	–
Vassilevski et al. [13]	–	–	1.10	1.45	–	–
Aboelfotoh et al. [14]	–	–	–	–	1.06	1.08
Sefaoğlu et al. [15]	–	–	–	–	1.25	1.00
Kazukauskas et al. [16]	–	–	1.05	0.74	–	–

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