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EBIC/PL investigations of dislocation network produced by silicon wafer direct bonding

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ABSTRACT

Dislocation networks (DNs) formed by silicon wafer bonding were studied by means of Electron Beam Induced Current (EBIC) and Photoluminescence (PL). The measurements were performed on p–n junction diode structures prepared by ion implantation. EBIC signal was observed not only inside the diode structure, but also far outside the diode area. This finding demonstrates the ability of the bonding interface to efficiently collect minority carriers and indicates a high electrical conductivity of the dislocation network. In addition, circular inhomogeneities of charge collection were observed. The contrast of those regions was bright at high beam energies and turned dark or vanished at lower energies. The contrast behavior of the circular areas can be explained by local variations of collection efficiency and recombination at the DN, which might be a result of different density of oxide precipitates. PL mappings at 0.794 and 1.081 eV revealed similar circular areas.

1. Introduction

Dislocations as active electrical components have been attracting the attention of the researchers for half a century [1]. However, controllable formation of the dislocations had been just a dream for a long time. It only recently became possible with the silicon wafer direct bonding technology.

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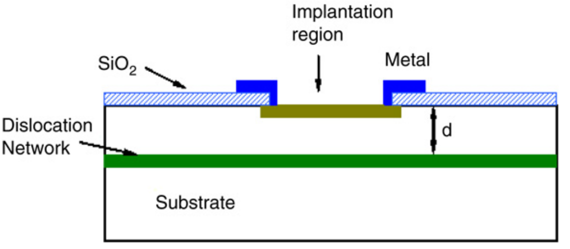

Fig. 1. (Color online) Structure of the test diode samples. The thickness *d* of the n-type samples is 2 μm and that of the p-type samples is 3 μm.

The technology allows fabricating a regular dislocation network (DN) at the bonding interface [2], and gives full control over the dislocation density and morphology by tuning the twist and tilt angles between the two initial wafers. The present interest in DNs is driven by their pronounced luminescence properties, originating mainly from the dislocation related luminescence [3] band D1-D4. The 1.5 μm emission wavelength of D1 renders DNs potentially applicable as active components in silicon based light emitters for on-chip optical interconnects [4]. Another feature of DNs is enhanced electrical conduction. Electron beam induced current (EBIC) investigation showed carrier transport over millimeter distance along DNs [5]. Strongly enhanced electrical conductivity has been also observed in MOSFETs devices containing DNs made on top of silicon on insulator (SOI) wafers [6]. Such behavior may be of substantial interest for novel electronic component [7].

In this work, EBIC and photoluminescence (PL) were performed to get inside detailed electrical, optical properties of DNs.

2. Experimental details

The DNs were formed by silicon wafer direct bonding technique. Wafers with the same type of doping were used, resulting in either n- or p-type substrates containing a DN plane parallel to the sample surface at a depth of several μm. The thickness of the top layer in n-type substrate samples was about 2 μm and about 3 μm in p-type substrate samples. Test p–n diodes were prepared by B^+ ion implantation at 50 keV into n-type bonded wafers and P^+ ion implantation at 135 keV into p-type wafers. In both cases the implantation dose was 1×10^{14} cm^{-2}. The implanted samples were subsequently furnace annealed at 1000 °C in N_2 atmosphere for 30 minutes, resulting in a junction depth of ∼400 nm for both type of wafers. A SiO_2 layer with a thickness of 500 nm was deposited on the surface by Plasma Enhanced Chemical Vapor Deposition (PECVD) for insulation of the contacts. The metal contact was made by deposition of Al, and then the samples were annealed at 420 °C in H_2 atmosphere to improve the contact quality. A sketch of the sample structure is shown in Fig. 1.

EBIC measurements were performed by using the Al contact on the front side and the ohmic contact on the rear side of the substrate prepared by rubbing InGa alloy. The samples were measured at various beam energies, at room temperature.

Light Beam Induced Current (LBIC) and PL measurements were performed using an Argon ion laser working at $\lambda = 514$ nm or a semiconductor laser working at $\lambda = 808$ nm as excitation sources. The excitation beam was modulated and Lock-in detection of LBIC and PL signal was used. In case of PL, the luminescence was spectrally analyzed in a monochromator and detected by a liquid nitrogen cooled Ge detector. Micrographs of LBIC and PL were taken by scanning the focused excitation beam across the sample.

3. Results

Fig. 2 shows EBIC images recorded in an n-type substrate sample at beam energies of 30 and 15 keV. The p–n junction region is clearly seen between the two rectangles formed by the Al contacts. Surprisingly, EBIC signal was detected not only in the p–n junction area, but also far outside the p–n