Observation of spatial distribution of vacancy defects in semiconductor by positron microscope and electron beam induced current measurement

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Observation of spatial distribution of vacancy defects in semiconductor by positron microscope and electron beam induced current measurement

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Abstract. A complementary study of vacancy defects in Si substrates by using scanning positron microscope (SPM) and electron beam induced current (EBIC) method were demonstrated for the same samples and in the same chamber. Both the S parameter and EBIC contrast were found to be enhanced in the regions containing vacancy defects introduced by ion implantation. That is, the SPM provides a criterion if the spatially resolved carrier recombination centres by the EBIC method are originating from vacancy defects or not.

1. Introduction

Electron beam induced current (EBIC) method provides the spatial distribution of defects in semiconductors [1, 2]. This method is based on a phenomenon that electron-hole pairs induced by electron bombardment in a depletion layer recombine at defects and hence the electric current is reduced near the defect region. As the result of persistent improvement, the current EBIC method can provide not only the lateral profile of defects but also the depth profile, the carrier lifetime and energy levels of defects [3, 4].

Scanning positron microscope (SPM) is a powerful tool for observing spatial distribution of vacancy defects near the subsurface region. We have constructed a SPM by using a specially fabricated small source and a solid neon moderator [5-8]. In our system, both the positron and electron beams can be focused on the sample by an objective lens. That is, the simultaneous acquisition of the SPM and EBIC images is possible. From this, one can know if defects visualized as the EBIC contrasts are associated with vacancy defects or not. In this work, we demonstrate a complementary observation of vacancy defects in ion implanted Si by using SPM and EBIC.

2. Experimental setup

2.1 SPM system

Figure 1 schematically shows our SPM apparatus. Sodium-22 of 330 MBq was deposited into a 2 mm-diameter hole and sealed by a cap with a Ti window of 5 μm thick. The source is cooled down to 4 K and a solid neon film is grown on the source window as a moderator [9]. The positron beam with the energy of 20 keV is focused onto a sample surface using a commercial scanning electron microscope optics. The positron beam is laterally scanned by moving the sample. The Doppler broadening of annihilation radiation (DBAR) spectra are obtained using a Ge detector. These DBAR spectra are

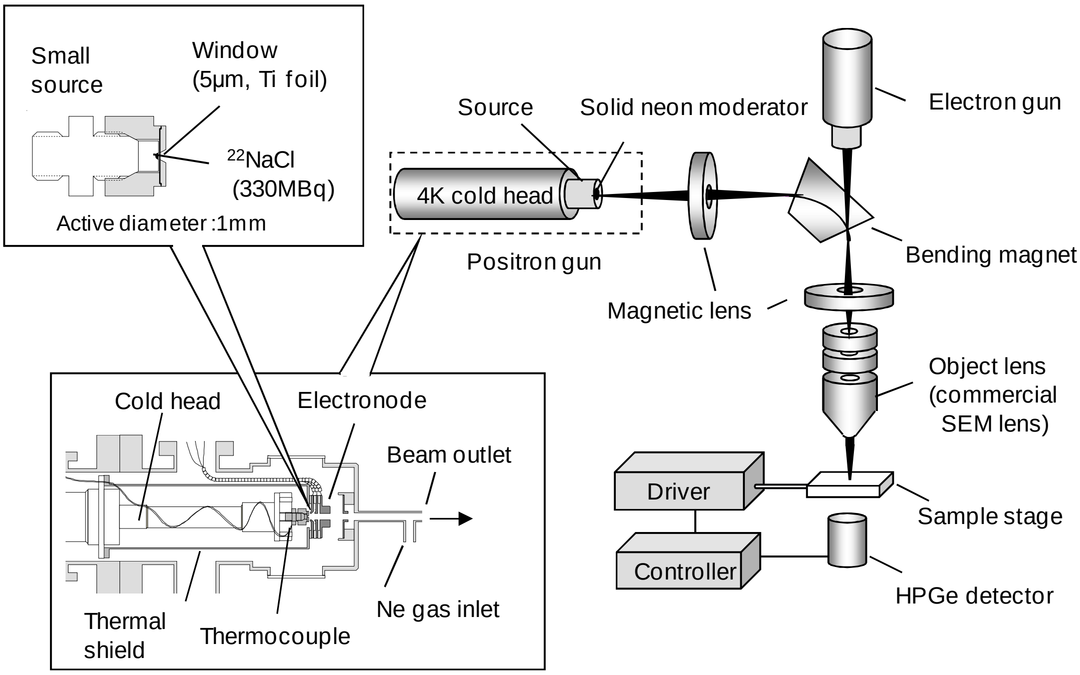

Figure 1. Schematics of our scanning positron microscope.

characterized by so-called S parameter, which is defined by the ratio of the intensity at the center of the energy peak of DBAR spectrum. The energy window for S parameter was 510.2 to 511.8 keV. All the S parameters were normalized to those in the Si substrate.

2.2 EBIC measurement system

Figure 2 shows the schematics of the EBIC measurement system. A commercial electron gun is installed at the branch of positron microbeam and the electron beam is focused onto the sample. The beam property should be almost the same as that of the positron beam because the same optics is used. Samples are mounted on an insulating holder connecting to the biased electrometer (ADCMT model 8252). Electrons and holes induced by electron bombardment are collected as the EBIC current by an

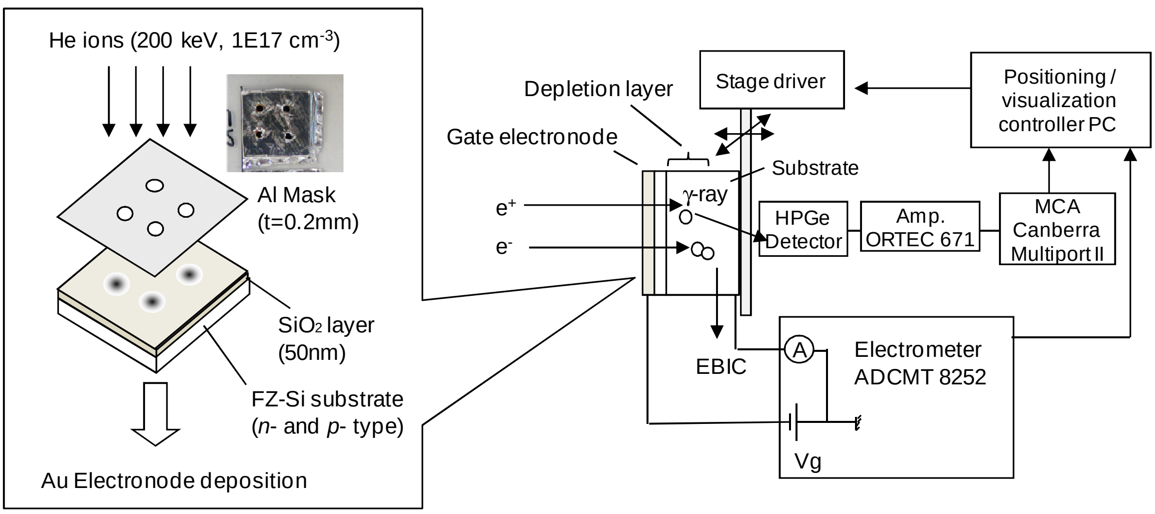

Figure 2. Schematics of the sample and the measurement setup.

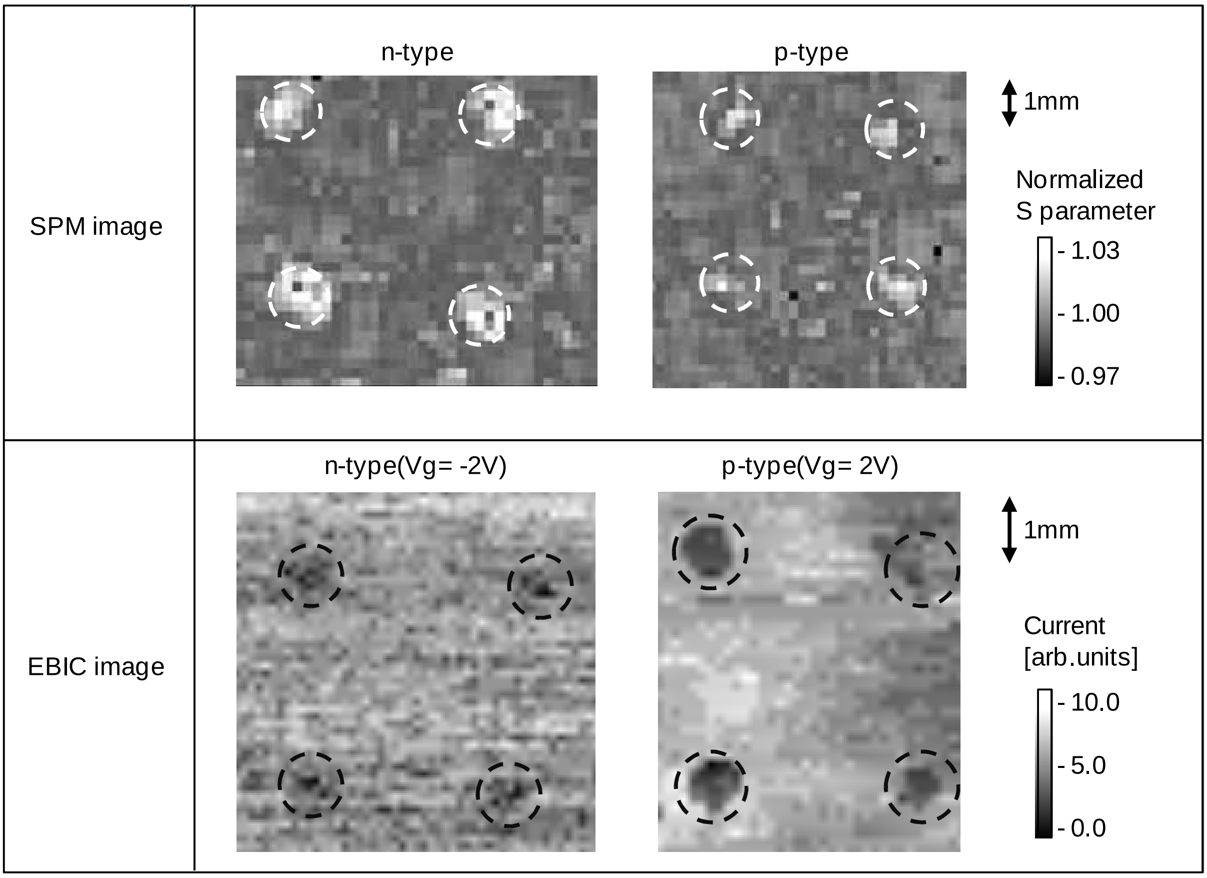

Figure 3. Distributions of S parameter and corresponding EBIC images.

internal electric field. If defects exist in the injected area, they mediate the electron-hole recombination. Consequently, by scanning the electron beam in lateral directions, defects in the injected area are visualized as dark contrasts.

2.3 Sample preparation

Samples used in this work were *n*- and *p*- type Si crystals (10x10 mm) with SiO_2 film of the thickness of 50 nm. Helium ion implantation was carried out through an aluminium mask with four holes as shown in Fig. 2. After implantation, Au gate electrodes and ohmic contacts were fabricated on the front sides and backsides, respectively, of the samples.

3. Results and discussion

Figure 3 shows the EBIC and SPM images for the *n*- and *p*-type Si samples. In the ion-implanted regions, dark contrasts are observed when the gate bias, which induces the depletion layer, was applied. This means that implantation-induced defects act as carrier recombination centres. In the ion-implanted region, S parameter also increases. This is attributed to the annihilation of positrons at vacancy defects introduced by the ion implantation. In the *p*-type sample, increase in S parameter is smaller as compared to the *n*-type sample. This may be because the charge state of vacancy defects is more positive in the *p*-type sample.

Figure 4 shows that the DBAR spectrum obtained in the high S parameter region (inside the circle in Fig.3) and several theoretical DBAR spectra of V2 (divacancy), V18 (vacancy cluster), V2+He and V2+2He (complex of divacancy and He atoms) defect structures [10, 11]. The experimental DBAR

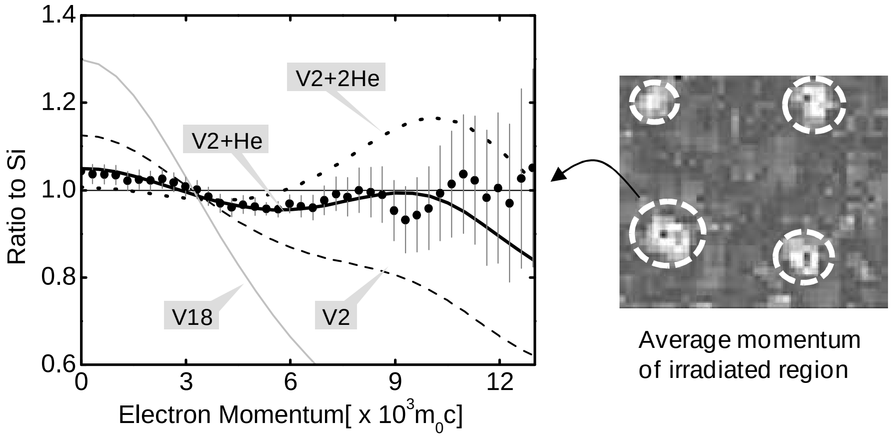

Figure 4. DBAR spectrum in the high S parameter region expressed as a ratio curve to the unimplanted Si. Theoretical curves for several defect structures are also shown.

spectrum is differentiated by the spectrum of the unimplanted silicon. Similarly, the theoretical DBAR spectra are differentiated by the spectrum of the perfect Si. Within these models, the divacancy occupied by one He atoms (V2+He) better reproduces the experimental result.

4. Summary

In this study, we demonstrated the simultaneous SPM and EBIC observations for the same samples and in the same chamber. Using the ion-implanted Si, the SPM observation showed that defects observed in the EBIC images contain vacancy defects. The combined SPM and EBIC method, that can provide spatial distribution of electrical active vacancy defects, is expected to be an important evaluation tool in the semiconductor device process.

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