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Competition between internal and heavy doping gettering options in epi-silicon

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Abstract

By studying the competition between internal and p^+ gettering, it was possible to identify the unwanted contaminant and estimate its concentration in unintentionally contaminated Si epi-structures simultaneously submitted to both gettering options. The contaminant concentration in the thermally untreated samples was below the DLTS detectability limit. Stratigraphic DLTS on thermally treated samples and EBIC study of the internal gettering allowed to establish that the contaminant was Fe. The occurrence of internal gettering even in presence of p^+ gettering in p/p^+ epi-structures suggested that the initial Fe concentration could have been in the range $\sim 1.5\times10^9$–$5.2\times10^{10}\,\mathrm{cm}^{-3}$. Internal gettering is effective in p^+ substrate because of the low onset temperature of p^+ gettering.

Keywords: Si; Gettering; EBIC; DLTS

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1. Introduction

Gettering options in Si include internal and external gettering, p^+ gettering, proximity and phosporous gettering [1–3]. Widely used are internal and p^+ gettering. For internal gettering (IG) a supersaturation of the contaminant is needed in a region containing oxygen precipitates where the impurity precipitates. A diffusion flux of the contaminant is thus established from a nearby region enriched with it and such region remains depleted of the impurity.

The driving force for p^+ gettering is the difference in electrochemical potential $\mu = kT\ln(C/C_0)$ between a p region and an adjacent p^+ region for the same dissolved concentration, C, of the impurity [1]. This is because the impurity equilibrium solubility C_0 is higher in the p^+ region than in the p one. The region of higher solubility is a sink for impurities from the lower solubility region. Also, due to the low position of the temperature-dependent Fermi level in the p^+ region the impurity interstitials M become ionized and experience a Coulomb attraction by the ionized acceptors A, and form MA pairs that immobilize and neutralize the M impurity [1,4].

Many of the published works on gettering of metals (e.g. Fe, Cu, Ni) in Si concern intentionally contaminated samples with high metal concentrations. Little exists on samples with no intentional contamination at low concentrations. In this paper, we report on the competition between internal and p^+ gettering simultaneously applied to Si epi-structures not intentionally contaminated, and with

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an initial impurity concentration below the detectability limit of deep level transient spectroscopy (DLTS), with the aim to determine the type and concentration of the unwanted contaminant.

2. Experimental

The p epi-silicon (resistivity $\rho = 10\,\Omega\,\text{cm}$) has been deposited on B-doped CZ Si substrates with either high (p^+, $\rho = 5-10\,\text{m}\Omega\,\text{cm}$) or low ($p^-$, $\rho = 10-20\,\Omega\,\text{cm}$) doping level. The substrates had an oxygen precipitate density ranging from $10^7\,\text{cm}^{-3}$ (p^- case) to $10^{10}\,\text{cm}^{-3}$ (p^+ case). The precipitates were localized at a depth of ~27–30 μm from the top surface. The epilayer was 2 and 4 μm thick for the p/p^- and p/p^+ case, respectively. The samples have been subjected to a 64 MDRAM device thermal simulation for a total thermal cycle of 23 h, with temperatures ranging from 750 to 1100 °C.

The samples were investigated by electron beam induced current (EBIC) and DLTS by using Al Schottky diodes. EBIC was used to evaluate the IG efficiency by measuring the contrast at the oxygen precipitates as a function of temperature between 77 and 300 K.

DLTS was applied to both untreated (i.e. before gettering occurred) and thermally treated samples. In the latter case, DLTS was carried out in: (a) the as-received epi-structures and (b) samples chemically etched down to a depth of ~27–30 μm from the top surface, i.e., to the beginning of the precipitate zone (stratigraphic DLTS). The DLTS spectra were collected in the 40–300 K temperature range. The standard sensitivity of DLTS was around $1\times10^{11}\,\text{cm}^{-3}$. However, due to the good quality of our diodes and by using very low temperature scans (0.03 K/s) a sensitivity of about $5\times10^{10}\,\text{cm}^{-3}$ could be obtained.

3. Results

Fig. 1a is the EBIC image at 300 K of a p/p^+ sample with a precipitate density of $1\times10^{10}\,\text{cm}^{-3}$. The curve of the EBIC contrast C at the oxygen precipitates as a function of the temperature T is given in Fig. 1b. The precipitates exhibit high contrast at all temperatures up to 300 K. The contrast curve has a positive slope $\mathrm{d}C/\mathrm{d}T$ as C increases with T. A similar C vs T behaviour was also observed in the sample p/p^- with a precipitate density of $1\times10^7\,\text{cm}^{-3}$.

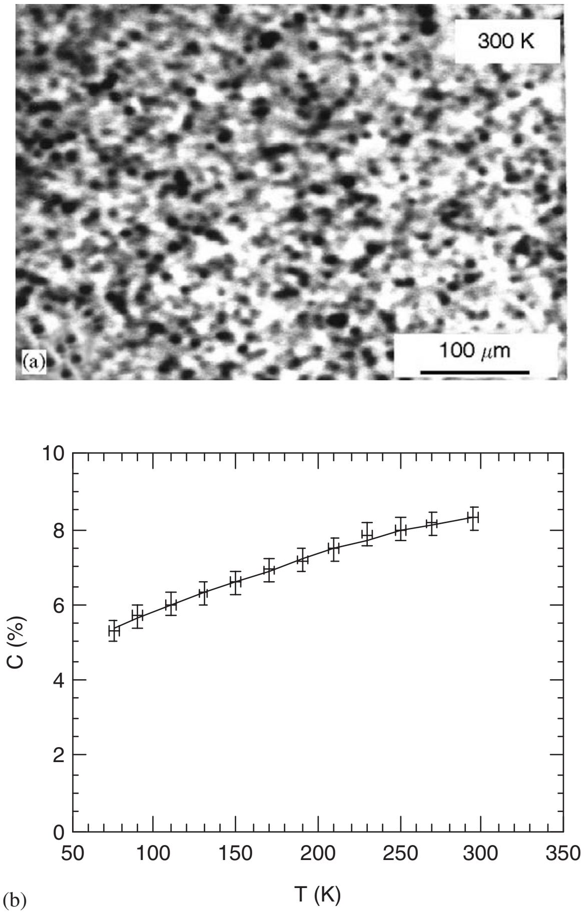

Fig. 1. (a) EBIC image at 300 K of the p/p^+ sample. (b) Curve of the EBIC contrast at the oxygen precipitates as a function of temperature in the 77–300 K range in the same sample.

By DLTS, no peak was detected in both the epi-structures not subjected to the thermal simulation and those submitted to it.

Fig. 2 shows a DLTS spectrum of a heat-treated p/p^- sample with the lowest density of oxygen precipitates after removal of 29 μm of material. This spectrum is thus taken from the substrate where impurities are expected to have diffused during thermal treatment. Here, the Fe–B peak with activation energy of 0.10 eV was detected.

4. Discussion

The positive slope of EBIC contrast curves like the one in Fig. 1b has been ascribed to the decoration of the precipitates by impurities, with associated deep levels in the band gap [5–7]. By using the model by Kveder et al. [5] it turned out that the C vs T curve of Fig. 1b can be accounted