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Investigation of a combined platinum and electron lifetime control treatment for silicon

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ABSTRACT

In silicon, the effect of Combined Lifetime Treatment (CLT) involving platinum diffusion and subsequent electron irradiation is different from the separate treatments of platinum diffusion and electron irradiation, even the treatment of electron irradiation followed by platinum diffusion. In this paper, we investigated the experimental behavior of different kinds of lifetime treated samples. We found that the reverse leakage current (I_{rr}) increases with the increasing platinum diffusion temperature or electron irradiation dose in the separate treatments. Conversely, I_{rr} of the CLT samples decreased with rising platinum diffusion temperature at the same dose of subsequent electron irradiation. By deep-level transient spectroscopy (DLTS), a new energy level E7 (Ec −0.376 eV) was found in our CLT samples. The new level E7 suppresses the dominance of the deeper level E8 (Ec −0.476 eV), which is caused by electron irradiation directly and results in I_{rr}'s increase. The formation of the level E7 comes from the complex defect-combined effect between platinum atoms and silicon vacancies, and it affects device's characteristics finally. These research will be helpful to the development of platinum-diffused devices used in intense electron irradiation environments.

1. Introduction

Platinum diffusion and electron irradiation are common methods to enhance the homogeneous distribution of defects in the depth profiles of silicon power devices. The defects are used as recombination centers to introduce deep levels into the forbidden gap and reduce the lifetime of silicon devices [1]. In previous studies, the separate platinum diffusion or the separate electron radiation have been widely applied as a 'lifetime killer' in the fabrication of silicon devices [2,3]. Platinum, as a hybrid solute in silicon, can exist in the form of interstitial (Pt_I) and substitutional (Pt_S) configurations. Pt_S is an electrically active configuration with an acceptor level of E_C −0.23 eV and donor level of E_V +0.32 eV [2]. Electron irradiation can induce displacements and defects in the semiconductor to drive silicon atoms out of their normal lattice positions and form vacancies and interstitial silicon atoms. Because of the existence of impurities in a material, defects can be induced under electron irradiation, such as oxygen vacancy ($VO^{(-/0)}$), double charged divacancy ($V_2^{(=/-)}$), H-related ($VOH^{(-/0)}$), and single charged divacancy ($V_2^{(-/0)}$) defects [4–6].

The effects of electron irradiation followed by platinum diffusion have been well studied [2]. However, platinum diffusion before electron irradiation, called the Combined Lifetime Treatment (CLT), is still under investigation. In this work, we first investigate the unexpected influence of electron irradiation on the reverse characteristics of ready platinum-diffused samples. Then we give the results of deep-level transient spectroscopy (DLTS) measurements. Finally, we provide a tentative explanation for the above experimental observations.

2. Experimental

In this work, 1200 V/30 A TO-220 plastic-sealed $P^+N^-N^+$ fast recovery diodes (FRD; Jilin Sino-Microelectronics Co., China) were used as the semiconductor devices. These devices were fabricated on lightly phosphorus-doped epitaxial silicon layers with a thickness of 100 μm and resistivity of 70 Ω·cm. Each epitaxial layer was grown on a heavily doped N-type (N^+) Czochralski (CZ) substrate, which was ⟨1 1 1⟩ oriented with a thickness of 500 μm and resistivity of 0.002–0.004 Ω·cm. The P-N junction area of the diodes is 0.1 cm^2.

For the separate platinum treatment, platinum diffusion was performed after P^+ boron diffusion by sputter depositing a 99.99%

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platinum film on the rear surface of substrates. Platinum drive-in diffusion was carried out in dry nitrogen at 870–900 °C for 1 h to form platinum U-shaped profile. For the separate electron irradiation treatment, samples were irradiated with a dose of electron fluency from 1.2×10^{14} to 4.8×10^{14} cm^{-2} using a 10 MeV electron linear accelerator at room temperature. And the CLT samples were achieved by platinum drive-in diffusion and subsequent electron irradiation in the above range of temperature and dose. After high-energy irradiation, all samples were annealed at 300 °C for 1 h to form a stable defect level.

The reverse leakage current of all samples was measured by a testing system including a Sony Tektronix 370A curve tracer at a reverse voltage of 1200V and the temperature of 125 °C, each result was the final result of five samples. DLTS measurements were performed on a PhysTech FT-1030 for three kinds of samples which were fabricated using separate platinum diffusion with 890 °C, separate electron irradiation with a dose of 3.6×10^{14} cm^{-2}, and the Combined Lifetime Treatment by platinum diffusion at 890 °C with subsequent electron irradiation of 3.6×10^{14} cm^{-2}. These samples were measured using the same filling pulse bias (V_P), reverse bias (V_R), and filling pulse width (T_P).

3. Results and discussion

The reverse leakage current of each FRD is composed of three parts, including the reverse diffusion current (I_D), surface leakage current (I_S), and space–charge region current (I_{sc}). Among these three components, I_D and I_S contribute little to the total reverse leakage current (I_{rr}) at high temperature. Therefore, I_{rr} approximately equals I_{sc} at high temperature. According to Eqs. (1)–(3), I_{sc} is inversely proportional to the space–charge generation lifetime (τ_{sc}), which is determined by the level position of introduced defects and carrier lifetime. And the lifetime directly depends on the defect density and capture coefficients [11]. The formula used to determine τ_{sc} is shown in Eq. (2). Furthermore, I_{rr} can be calculated from τ_{sc} as indicated in Eq. (1) [7].

$$I_{sc} = qAW_D n_i/\tau_{sc} \tag{1}$$

$$\tau_{sc} = \tau_{n0} e^{(E_i - E_r)/kT} + \tau_{p0} e^{(E_r - E_i)/kT} \tag{2}$$

$$\tau_{n0} = \frac{1}{C_{Tn} N_r} = \frac{1}{\vartheta_{Tn} \sigma_{cn} N_r} \tag{3}$$

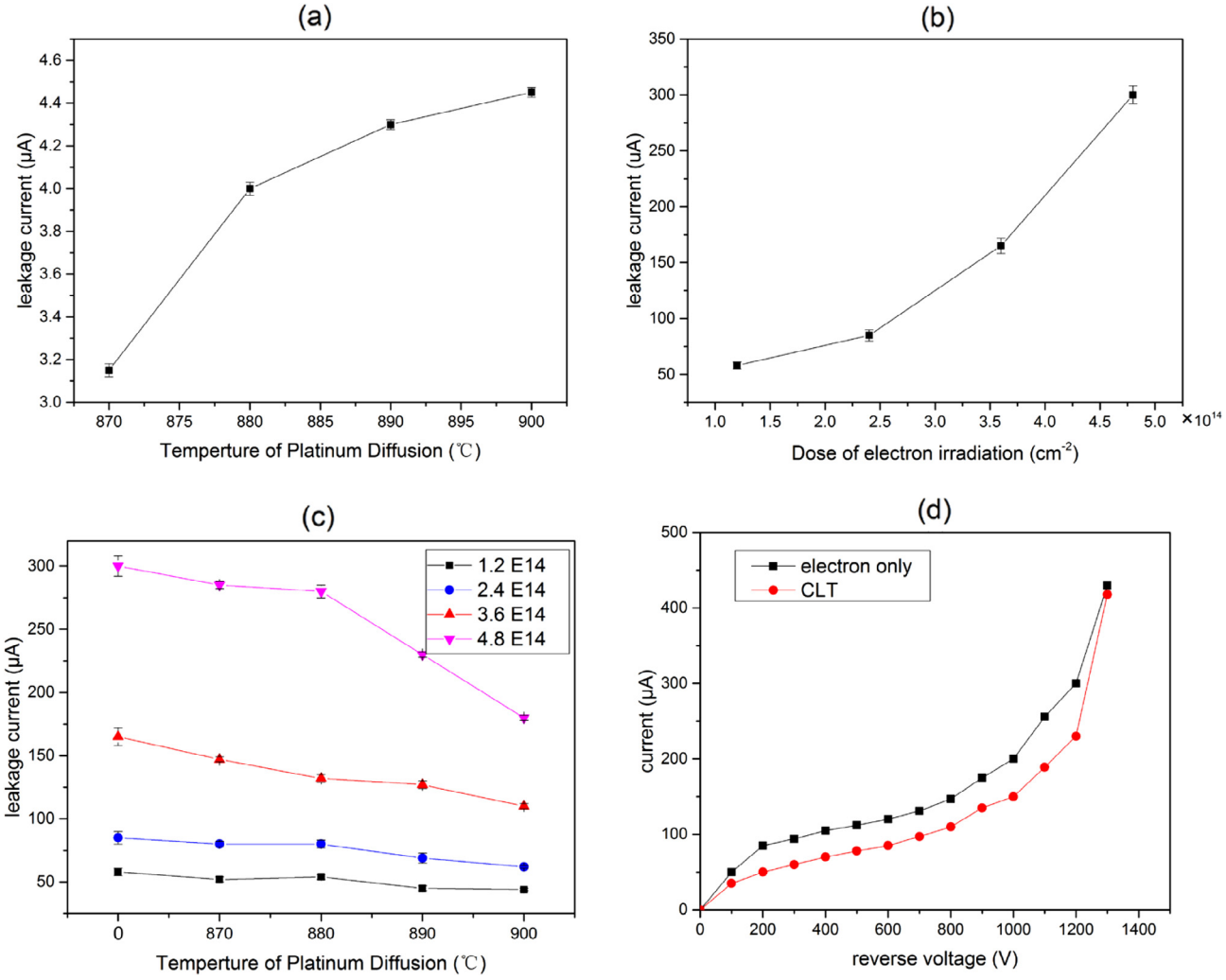

Fig. 1. (a) Platinum diffusion temperature dependence of the leakage current of the FRD treated by separate platinum diffusion. (b) Electron irradiation dose dependence of the leakage current of FRD exposed to separate electron irradiation. (c) Platinum diffusion temperature dependence of the leakage current of CLT FRDs exposed to different doses of electron irradiation at (0 °C means no platinum diffusion). (d) Reverse I-V curve of FRD treated by separate electron irradiation of 4.8×10^{14} cm^{-2} and CLT FRD of platinum diffusion temperature at 890 °C and electron irradiation dose of 4.8×10^{14} cm^{-2}. (All the data shown in this figure were tested at the temperature of 125 °C).