Distribution of Electrically Active Nickel Atoms in Dislocation-Free N- and P-Type Silicon Crystals Measured by Deep Level Transient Spectroscopy

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Abstract

Distribution profiles of electrically active nickel atoms in n-and p-type dislocation-free silicon are measured by means of the deep level transient spectroscopy (DLTS) on Schottky barrier diodes (SBD) fabricated on nickel-doped silicon. The processes of lapping-off the surface, etching, SBD formation and DLTS measurement were repeated on one sample until the total removed-off thickness exceeded the half of the initial sample thickness. The distribution profiles were evaluated by measuring the concentrations of the electron trap (nickel acceptor level) in n-type and the hole trap (nickel donor level) in p-type silicon as functions of x / l, where x is the distance from the surface and l is the sample thickness.

The distributions manifest U-shaped diffusion profiles irrespective of one-sided or double-sided diffusion conditions. The experimental results have shown, in the bulk, the flat profiles peculiar to those according to the dissociative mechanism of diffusion in which the sinks and sources of lattice vacancies are present in the bulk.

Keywords: *nickel distribution, dislocation-free silicon, n-silicon, p-silicon, U-shaped profile, DLTS*

1. Introduction

Nickel is known as one of the fastest diffusing elements in silicon among 3d transition-metal impurities. A large fraction of total nickel atoms dissolved into a silicon crystal stays at interstitial sites and precipitates in the bulk[1,2] during the heat treatment at high temperature or during quenching. The rest fraction not more than 10^{-3} of total contents, which stays at substitutional sites[1,2], is electrically ionizable, or electrically active. Interstitial nickel atoms (Ni_i) have been recently reported[3] to be predominantly neutral, or electrically inactive. The substitutional nickel atoms (Ni_S) in silicon introduces[4,5] an acceptor level at $E_C - 0.47$ eV and a donor level at $E_V + 0.18$ eV, where E_C and E_V are energies of the bottom of the conduction band and the top of the valence band, respectively.

Because nickel atoms occupy both interstitial and substitutional sites, the diffusion of nickel atoms is accompanied by the site exchange between interstitial and substitutional sites including intrinsic point defects. Not only in dislocated silicon[6] but also in dislocation-free silicon[7,8], the site exchange mechanism of nickel atoms in silicon has been reported to be due to the dissociative mechanism in which the dominant point defects acting on the site exchange are vacancies.

In the present study, the distribution of the concentration, C_S, of Ni_S in dislocation-free n-and p-type silicon crys-

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tals are measured by deep level transient spectroscopy (DLTS) on a Schottky barrier diode (SBD).

2. Experimental

The silicon crystals used for the experiment were phosphorus doped n type and floating zoned silicon in both dislocated and dislocation free silicon. Phosphorus content in these crystals was 2.7 X I o^{i}: to 1.2X 10^{14} cm ^{3} in dislocated silicon and ran°ed from 1 1X 10^{13} to 1.4 X 10^{14} cm $^{-3}$ in dislocation free silicon.

Nickel was evaporated only onto one side of surfaces of silicon slices because it has been already confirmed ex perimentally [91] that C_s shows identical U shaped diffusion profile irrespective of one sided or double sided diffusion conditions. The evaporated side is referred to as the front side and the opposite surface is referred to as the rear side.

Nickel diffusion was carried out in flowing nitrogen gas ambient. The diffusion temperature T0 and mffusion time t0 are T_0 = 980℃ and t_0 = 10, 30 and 120 min for n type silicon, and T0 = 950℃ and t_0 = 15, 30 and 60 min for p type silicon.

After the heat treatment, the slice was lightly lapped and etched to remove nickel silicide and silicon oxide layer from the front side. In the present paper, x = 0 refers to this lapped and etched front side, where x is the distance from the surface. The rear side was never treated after thin layer was once grinded off and etched off.

The DLTS measurements were performed on an SBD formed by means of gold evaporation on n type and alumi num evaporation on p type silicon with a reverse bias of 5 V, a filling pulse bias oro V, a rate window of0.5/5.0 ms and an injection pulse bias of 500μs. The concentration of Cs was evaluated from the peak height of the DLTS associated with the nickel acceptor level in n type and the nickel do nor level in p type silicon, and steady state capacitance.

To obtain the distribution of Cs, the processes of lapping off the surface, etching, SBD formation and DLTS measurement were repeated on one sample until the total removed off thickness exceeded the half of the initial sam ple thickness.

3. Results and Discussion

Typical DLTS signals are shown in Fig. 1 for nickel doped n type silicon and in Fig. 2 for nickel doped p typc silicon. The DLTS peak observed at about 270K is identi fied as the signal due to an electron emission process at a nickel acceptor level (electron trap B [5]). The activation en crgy of electron emission is E_e 0.47 cV which is in good agreement with the value reported in references 4 and 5. In

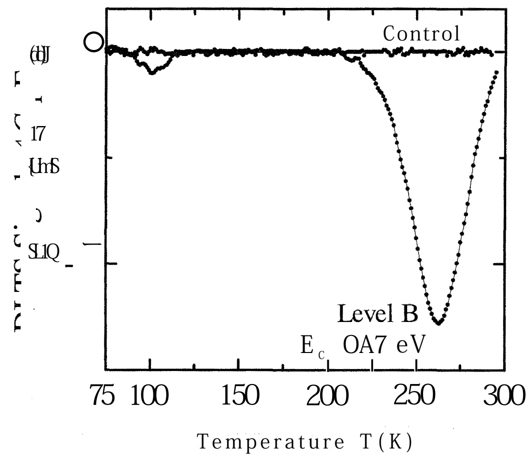

Fig. 1. DLTS spectrnm of n type silicon doped with nickel with T0 = 980℃ and t_0 = 10 min at x / l = 0.086 with l = 0.150cm.

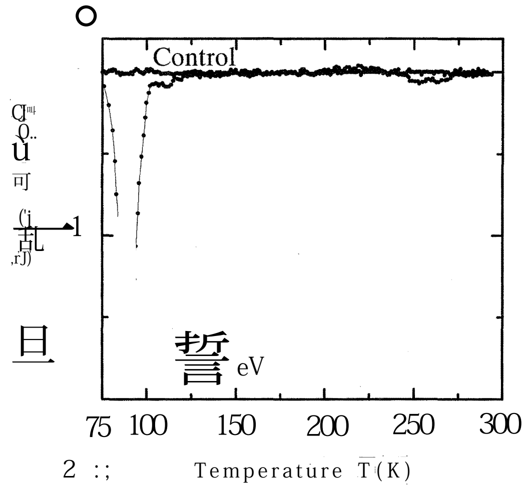

Fig. 2. DLTS spectrum of p type silicon doped with nickel with T0 = 950℃ and t_0 = 10 min at x / l = 0.061 with l = 0.120cm.

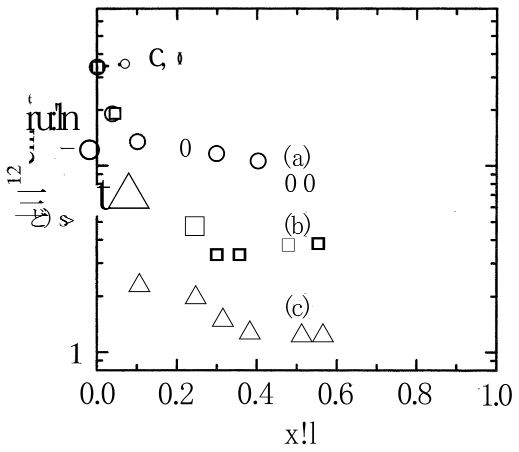

Fig.3. Distribution of C_s inn type silicon. t_{II} = 120 min (a), 30 min (b) and 10 min (c) at TD= 980 °C.

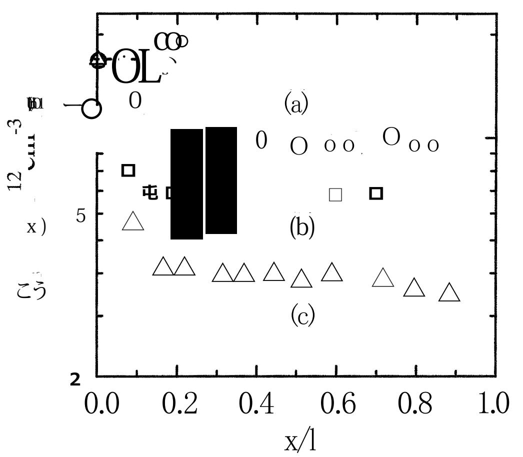

Fig. 4. Distribution of C_s in p type silicon. $I_{r,}$ = 60 nlin (a), 30 min (b) and 15 min (c) at T_D = 950t:.

nickel doped p type silicon, the DLTS peak at about 90K is identified as the signal due to a hole emission process at a nickel donor level (hole trap C"). The hole emission activation energy of the nickel donor level is E_v + 0. 18 eV as shown in Fig. (2). This value is in good agreement with that reported in reference, 4 and 5.

The distribution profiles of C, are evaluated by measuring the concentrations of the electron trap B inn type and the hole trap C in p type silicon as function of x I I, where I is the sample thickness. The experimentally obtained distributions of C_s are plotted in Fig. 3 for the electron trap B and in Fig. 4 for hole trap C. Roughly speaking, the distributions in both Figs. 3 and 4 manifest U shaped profiles though only the half of the entire profiles are shown. In addition, the profiles of the electron trap B and hole trap C are qualitatively alike. Such a similarity is to be expected only when the two trap levels are due to the different charge state of the same nickel atom, 0 an amphoteric nickel center.

Reg,trding a theoretical consideration, theoretical calculation based on the dissociative and kick out mechanisms of diffusion is currently in progress. It should be noted that the experimental results show the flat profile in the crystal bulk. Such flat profiles are peculiar to the profiles according to the dissociative mechanism of diffusion in which the sinks and sources of lattice vacancies are present in the hulk.

In summary, the distribution o substitutional nickel atoms in dislocation free n and p type silicon has been measured by means of DLTS method. The experimental results show the flat profiles peculiar to those according to the dissociative mechanism of diffusion in which the sinks and sources of lattice vacancies are present in the bulk.

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