IMPROVEMENT OF RADIATION HARDNESS OF CZ-Si P-N JUNCTIONS BY HYDROGEN ION-BEAM TREATMENT

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Improvement of radiation hardness of silicon solar cells for space usage is one of the important tasks of modern silicon material science. In the present work the influence of treatment by low energy hydrogen ions and subsequent electron irradiation on the spectral response and diffusion length of minority carriers L_D of silicon p-n junctions was investigated. In our experiments we used boron doped single-crystalline Cz-Si wafers of different quality with diffusion length $L_D \sim$ 25-200 μm. L_D was estimated from spectral response measured at the specially manufactured p-n junctions (solar cells without antirflective coating) formed at a depth of 0.5 μm due to phosphorous diffusion at 900 ^oC. Ohmic contacts were provided by silver screen-printing process.

Hydrogenation of samples was carried out by hydrogen ions with energies 50-4000 eV at temperatures 25-350 ^oC. Treatments with the current density of 100 μA/cm^2 for 5-40 min provided the fluences of incorporated hydrogen ions from $1.9 \cdot 10^{17}$ to $1.5 \cdot 10^{18}$ cm^{-2}. To check radiation hardness changes, the unhydrogenated and hydrogenated samples were subjected to 1 MeV electron irradiation with the fluences $(0.1\text{-}3) \cdot 10^{15}$ cm^{-2}.

As our experiments have shown, energy of ions is most critical parameter for modification of L_D due to hydrogenation. Besides, L_D as a function of the energy is strongly dependent on the initial L_D of samples. For example, for low-L_D (25-75 μm) substrates L_D exhibited an increase practically at every treatment regime for energies not higher than 500-600 eV. At the same time, for higher-L_D (100-200 μm) substrates the result was strongly dependent on the energy of ions, causing the energy threshold exceeding which L_D decreased at all treatment regimes. For the studied samples with $L_D \sim$ 150-200 μm the threshold value of hydrogen ion energy was about 150-200 eV. In particular, for the samples with $L_D \sim$ 200 μm radiation by hydrogen ions with under-threshold energies have resulted in increase of L_D up to 15-20 % after 2-5 min hydrogenation even at room temperatures. Note that elevation of hydrogenation temperature up to 200-350 ^oC or subsequent annealing in hydrogen-containing ambient at 350 ^oC for 10 min after room-temperature hydrogenation resulted in additional increase of L_D for the same times of hydrogenation.

As is known, the atomic hydrogen incorporated into silicon at low enough temperatures is partly transformed into the molecular state and introduce insignificant changes in the properties of the material. Production of mobile vacancies at hard irradiation of Si near such molecule may lead to its decay into atomic constituents [1]. Having higher diffusivity, the latter can passivate the nucleated radiation defects. As one might expect, this self-passivation effect will cause lesser degradation of silicon parameters. To check experimentally this idea, the initial (unhydrogenated) and hydrogenated samples were irradiated by 1 MeV electrons. As is evident from our experiments, β-irradiation with the fluence 3×10^{14} reduces L_D by a factor of six, while for the hydrogenated ones it is only halved. Probably this can be considered as a direct evidence that treatment of silicon p-n junctions (solar cells) by hydrogen plasma significantly improves their radiation hardness.

1) S.K. Estreicher, Materials Science and Engineering Vol. R14, 319 (1995)

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