ドーピングレベルに依存する Si 中の積層欠陥と Na 原子の相互作用

Interaction of Na atoms with stacking faults in Si crystals with different doping levels 東北大金研¹, 名大工²^O大野裕¹, 森戸春彦¹, 沓掛健太朗¹, 米永一郎¹, 横井達矢², 中村篤智², 松永克志² IMR, Tohoku Univ.¹, GSE, Nagoya Univ.², ^oYutaka Ohno¹, Haruhiko Morito¹, Kentaro Kutsukake¹, Ichiro Yonenaga¹, Tatsuya Yokoi², Atsutomo Nakamura², Katsushi Matsunaga²

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It is believed that the key factor of the PID in *p*-type Si solar cells is sodium (Na) atoms existing inside and on solar module encapsulation, as well as on Si cells. During operation, those Na atoms would be accumulated at the interface between the antireflective coating layer and Si, and they agglomerate at stacking faults (SFs) in Si expanding from the interface [1]. Na atoms accumulated at the interface would spontaneously diffuse into SFs and create an electrically conductive layers [2]. This can provide a high conductivity between *n*-doped emitter and *p*-doped base when the SFs penetrate the *n-p* junction, resulting in a significant reduction of the shunt resistance which degrades the solar cell performance [1]. Those SFs would nucleate from microscopic defects at the interface, during the PID stress under the influence of Na penetration [3]. Also, the Na penetration process would be modified depending on the doping level [4]. These results suggest that the formation energy of SFs varies depending on the doping level, as well as on the existence of Na atoms. In the present work, we have examined the interaction of Na atoms with SFs in Si crystals with different doping levels, leading to a reduction in the SF formation energy.

SF ribbons bound by pairs of partial dislocations were intentionally introduced into three kinds of Czochralski-grown Si crystals, i.e., B-doped *p*-type Si (with a concentration of 8×10^{18} cm⁻³), P-doped *n*-type Si (3×10^{19} cm⁻³), and nominally undoped n-type Si, by applying a compressive stress at an elevated temperature of 1173 K for 0.5 h [5]. Each crystal and a Na sample were sealed within a stainless steel tube with Ar gas, and the crystal was doped with Na atoms by heating the tube in a furnace at 973 K for 5 h [6]. The width of each SF ribbon w_{SF} was estimated, by transmission electron microscopy, as a function of the line orientation α (i.e., the angle of **b** to **u** in which **b** is the sum of the Burgers vectors of the dislocations bounding the SF ribbon and **u** is a vector along the dislocations), and the SF formation energy E_{SF} was calculated with $w_{SF}(\alpha)$.

In all the examined crystals, $w_{SF}(\alpha)$ increased by Na doping, and the ratio between the $w_{SF}(\alpha)$ after Na doping and that before doping was almost independent of α . Therefore, Na atoms would agglomerate at the SFs due to an electronic interaction, rather than at the partial dislocations due to an elastic interaction, and the attractive electronic interaction results in the reduction of E_{SF} . The degree of the energy reduction would decrease with rising the Fermi level: E_{SF} was reduced by more than 10 mJ/m² in *p*-Si while it was scarcely reduced in *n*-Si. These results indicate that Na agglomerates at SFs in *p*-Si are fairly stable in comparison with in *n*-type one, and this is consistent with the PID phenomena in *p*-type solar cells. The doping-dependent interaction energy will be discussed theoretically by using *ab-initio* calculations.

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