Low Minority Carrier Lifetime at the Bottom of Quasi-single Crystalline Silicon

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Crystalline silicon including Czochralski (Cz) and multicrystalline (mc) silicon is the main materials for solar cells. For reducing the cost, quasi-single crystalline (QSC) silicon grown by directional solidification technique has been widely investigated in the last decade. QSC silicon combines both of the advantage of Cz and mc silicon and expects to produce lower cost and higher efficiency solar cells. However, it is reported that the lower minority carrier lifetime (< 2us) area at the bottom of QSC silicon ingots, so called the “Red Zone (RZ)” in industry, is larger than that of mc silicon ingots. Therefore, the coefficient of material utilization of QSC silicon ingots is usually 3-5% less than that of seed-assisted mc silicon ingots. Thus, the mechanism of low minority carrier lifetime at the bottom of QSC silicon has attracted much attention.

In this work, the RZ with low minority carrier lifetime at the bottom of QSC silicon ingots has been investigated. It is reported that the RZ in QSC silicon consists of two parts, i.e. part A and B as shown in Fig. 1. The part A is the remnant seed which is survived after melting of raw silicon materials, while the part B is the initial area of silicon crystal growth which is above the remnant seed. It is found that the oxygen concentration in QSC silicon is higher than that in normal mc silicon, and increases with the thickness increase of the Cz silicon seeds. Moreover, the width of part B also increases with the whole crystal growth time of QSC silicon. Those results indicate that the lower minority carrier lifetime in the part B may be mainly due to the higher oxygen concentrations which is originated from the molten Cz silicon seeds with higher oxygen concentrations and the diffusion of oxygen from the remnant seeds (part A). Moreover, the average efficiency of solar cells manufactured by the RZ wafers from QSC silicon ingots has achieved to above 19.60%, higher than that by normal wafers from seed-assisted mc silicon. Finally, it is also reported that the light induced degradation (LID) of those cells is lower than that of CZ silicon cells.

\textbf{Fig 1. The diagram of the red zone with lower minority carrier lifetime in the cross-section of a QSC silicon ingot.}