Analysis of subcell damage in proton irradiated triple-junction solar cells with time-resolved photoluminescence

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The energy supply of satellites and other space vehicles is mainly through conversion of solar energy into electricity via tandem solar cells, which have low weight but high performance due to spectral splitting.[1] In contrary to the environment a typical solar cell on earth is exposed to, the space environment is very harsh. High energetic electrons and protons irradiate the solar cell continuously and lead to device degradation due to atomic displacements and ionization.[2] An accurate knowledge of the damage mechanism is indispensable for successful space missions.

Depending on the particle energy and type, the penetration depth into the tandem cell is different.[3] It is known that the proton irradiation affects mainly the region where the proton stops. However, different regions can be damaged as well. Experimental data of degradation of current–voltage (I–V) curves is usually taken to investigate the lifetime of solar cells in space.[4] Since I–V curves can only characterize the device as a whole, the damaged region is estimated via calculation.[5] However, optical characterization of the sample is able to improve this point. We recently proposed that information of separation and recombination carrier dynamics in subcells can be obtained from power dependent photoluminescence (PL) decays.[6,7] The generation of non-radiative traps is directly reflected in the carrier dynamics. Therefore, the optical method conveniently determines the proton damage directly in each subcell of the tandem solar cell, and calculation of penetration depth is not necessary.

In this work, we measure PL decays from the top InGaP and middle GaAs subcell of triple-junction solar cells with different proton damage. The characteristic time constants are obtained from excitation power dependence and compared with the I–V curves of the total device. We explain how the time constants are related to the electrical properties of the subcell.

The data shows that the time constant reflecting the intrinsic recombination rate of the subcell is strongly influenced by the proton penetration depth. Fast PL decays are observed for subcells where the proton stops, which is consistent with previous results. An important point is that exceptions from this trend could be confirmed as well. We demonstrate that the time constants correlate very well with the electric properties such as shunt and series resistances. The time constants are also used to estimate the subcell conversion efficiencies for different damages as proposed earlier.[7] We conclude that the optical method experimentally determines the subcell damages, which is an advantage over the I–V method.

This work was supported by CREST, Japan Science and Technology Agency (JST).

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