CdTe is one of the most promising photovoltaic (PV) materials for use in low-cost, high-efficiency thin-film solar cells, because it has a direct band gap of approximately 1.5 eV, and because large-area, high-quality polycrystalline CdTe films can be prepared by simple and easy methods such as close-spaced sublimation (CSS) and vapor transport deposition (VTD). CdTe solar cells are usually fabricated in superstrate configuration. In contrast, CdTe solar cells in substrate configuration offer the possibility of choosing a variety of substrate materials such as inexpensive substrates and lightweight, flexible substrates.

In this work, we attempted to fabricate the substrate-type CdTe solar cells by CSS method. The formation of the CdS$_x$Te$_{1-x}$ mixed crystal layer in the CdS/CdTe interface is important for reducing the interface states at the CdS/CdTe interface, because there is a large lattice mismatch between CdTe and CdS. However, it is difficult to form the CdS$_x$Te$_{1-x}$ mixed crystal layer in substrate configuration, because the deposition temperature of CdS layer (~435°C) is lower than that of CdTe layer (~600°C). Therefore, we attempted to perform the heat-treatment after the formation of CdS/CdTe structure. Figure 1 shows junction photoluminescence (PL) spectra of the CdS/CdTe structures in substrate configuration with and without heat-treatment at 600°C for 60 min. The typical PL spectrum of the CdTe polycrystalline film and the typical junction PL spectrum of the CdTe solar cell in superstrate configuration are also shown for comparison. In the junction PL in substrate configuration without the heat-treatment, the almost same spectrum as the polycrystalline CdTe film was observed, which suggests that CdS$_x$Te$_{1-x}$ mixed crystal layer is not formed. On the other hand, in the junction PL of the heat-treated structure, peak wavelength shifted to longer wavelength, similar to the superstrate-type cell. This result indicates that CdS$_x$Te$_{1-x}$ mixed crystal layer is formed by the heat-treatment after the formation of CdS/CdTe structure at 600°C.

We fabricated the substrate-type CdTe solar cells on graphite substrates with and without the heat-treatment after the formation of CdS/CdTe structure, as shown in Fig.1. In the cell without the heat-treatment, 0.76% efficiency ($J_{sc}$: 7.0 mA/cm$^2$, $V_{oc}$: 0.440 V, FF: 0.237) was obtained. On the other hand, 1.5% efficiency ($J_{sc}$: 11.6 mA/cm$^2$, $V_{oc}$: 0.346 V, FF: 0.371) was obtained in the cell with the heat-treatment. This result indicates that the performance of the substrate-type CdTe solar cell improves due to the effects of the heat-treatment after the formation of CdS/CdTe structure.

Furthermore, we tried to fabricate the substrate-type CdTe solar cells using graphene back electrode on glass substrate, and 0.08% efficiency ($J_{sc}$: 0.555 mA/cm$^2$, $V_{oc}$: 0.530 V, FF: 0.262) was obtained. The performance of the cells using graphene back electrode was currently lower than that of the cells graphite substrate probably due to high series resistance, but the improvement of the open circuit voltage was observed.

This work was supported in part by a grant from the Futaba Electronics Memorial Foundation, Chiba, Japan.