Solar-pumped lasers (SPLs) convert broadband and noncoherent sunlight into laser light [1, 2], which allows us to transmit solar energy efficiently, as illustrated in Fig. 1 [3]. We have previously proposed the basic concept of the photovoltaic (PV) cells that receive the laser light and convert into electricity [4]. Crystalline silicon (c-Si) is suitable for the PV cell material, because the absorption edge is just below the SPL wavelength around 1060 nm. Inner resistance and Auger recombination are well reduced by using thin Si wafers around 50 µm, which in turn requires a light-trapping mechanism for sufficient light absorption. We have designed suitable light-trapping structures consisting of multilayered angle-selective filters on the front surfaces of the PV cells and diffuse reflectors on the rear surfaces, depending on the acceptance angle φ (the incident angle φ changes within φ ≤ φi), and demonstrated significant performance [5]. In the present study, we clarify the other requisites for the Si PV cells to achieve high efficiency of the laser-to-electricity conversion, from two points of view. One is the practical light-trapping effect on the thin PV cells, and the other is the impact of the electronic properties: bulk recombination lifetime, τbulk, surface recombination velocity, S, and contact resistance, Rc.

Using a device simulator PC-1Dmod ver. 6.2, we calculated conversion efficiency of two types of the Si PV cells: one is designed for stationary use and optical-fiber connection with φi = 10° equipped with a 32-layered double-cavity bandpass filter and the other for power transmission to moving objects with φi = 30° equipped with a 40-layered shortpass filter. The light-trapping effects were taken into account using a ray-trace simulation with the Monte-Carlo method. The filter structure was optimized for each case.

Using the cell for φi = 10° of just 50 µm in thickness with the rear surface reflectance Rc = 0.98, absorbance as high as 0.87 is achieved by optimizing the filter structure. Conversion efficiency is 51% under the 100 W/cm² laser illumination with τbulk = 100 µs, S = 1000 cm/s, and Rc = 0.1 mΩ-cm, as shown in Figs. 2 and 3. In particular to lower Rc is of great importance. Although it is challenging to realize these requisites for high efficiency simultaneously, it is feasible by tuning the present technologies for low S, like point contacts with laser firing, heterojunctions, and/or tunnel-oxide-passivated contacts, with the miniaturized cell concept for the direct optical-fiber connection and interdigitated back-contact structures using ribbed wafers for laser beaming in free space. When φi is larger, the light-trapping performance is less significant, and hence thicker Si wafers are required, resulting in a larger inner resistance, more remarkable Auger recombination, and consequently lower conversion efficiency. The absorbance and conversion efficiency of the 75-µm-thick cell designed for φi = 30° are 0.84 and 47%, respectively.

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