Rare-earth doped materials enhance silicon solar cell efficiency

Guillaume Alombert-Goget, Davor Ristic, Alessandro Chiasera, Stefano Varas, Maurizio Ferrari, Giancarlo C. Righini, Belto Dieudonne, and Brigitte Boulard

Doped glasses and glass ceramics may support effective down conversion of high-energy photons and provide better exploitation of the solar spectrum.

In silicon solar cells, the mismatch between the incident solar spectrum and the spectral absorption frequencies results in a major energy loss. Photons with energies smaller than the silicon band gap are not absorbed, and their energy is totally wasted. Photons with energies larger than twice the silicon band gap are absorbed, but the excess energy is lost to heating. Down-conversion and up-conversion mechanisms are usually exploited to modify the incident solar spectrum. Figure 1 illustrates the process schematically. In down conversion, multiple low-energy photons are generated to exploit the energy of one incident high-energy photon. In up conversion, two or more incoming photons generate at least one photon with a higher energy than the incoming photons.

We focus on the down-conversion mechanism. Rare earth (RE) ions, in which absorption and emission occur through a number of energy levels, allow down-conversion processes, as shown in Figure 2. Different mechanisms based on energy transfer between a RE$^{3+}$ (absorbing ion) and Yb$^{3+}$ (emitting ion) were investigated recently: Pr$^{3+}$/Yb$^{3+}$; Tb$^{3+}$/Yb$^{3+}$; Tm$^{3+}$/Yb$^{3+}$. Most studies of down conversion to date have been performed on single crystals characterized by a low phonon cut-off energy to minimize non-radiative transitions from the RE ions to the host matrix. Recent studies, however, have demonstrated that some glasses and transparent glass ceramics (GCs) could be valid alternative systems for supporting an effective quantum cutting process.¹

Figure 1. Solar spectrum showing the band gap and twice the band gap of silicon.² Down conversion shifts photons from a high-energy band (blue) to the maximum absorption band of silicon (white). Up conversion shifts photons from a low-energy band (red) to the maximum absorption band of silicon.

Figure 2. Rare earth ion down-conversion mechanism.³ (a) Quantum cutting on a single ion, A, by sequential emission of two photons. (b)-(c)-(d) Quantum cutting by a pair of rare earth ions via (partial) energy transfer from ion A to ion B, indicated by (1) and (2).
Silica–hafnia is a flexible system that has proven to be suitable for RE doping and fabrication of GC planar waveguides. In silica–hafnia GC, the RE ions are embedded in hafnia nanocrystals with a cutoff frequency of about 700 cm\(^{-1}\). To assess the energy transfer efficiency, we investigated 70SiO\(_2\)-30HfO\(_2\) planar waveguides activated by different amounts of Tb\(^{3+}\) and Yb\(^{3+}\) ions. We used decay curve analysis to evaluate the transfer efficiency. The highest energy transfer efficiency, 38%, was observed in 70SiO\(_2\)-30HfO\(_2\) GC films activated by 1% Tb\(^{3+}\) and 4% Yb\(^{3+}\).

Our research revealed that heavy-metal fluoride glasses provide a superb host when both a low phonon energy and a high RE content are required. On the other hand, ZLAG glass (70ZrF\(_4\) 23.5LaF\(_3\) 0.5AlF\(_3\) 6GaF\(_3\) mol%) yields GC through spinodal decomposition. These glasses and GC, doped with RE = Er\(^{3+}\), Yb\(^{3+}\), and Pr\(^{3+}\) have been successfully obtained as thin films by the use of physical vapor deposition. We assessed the energy transfer efficiency of ZLAG glasses activated by different molar percentages of Pr\(^{3+}\)/Yb\(^{3+}\). We obtained efficient down conversion in bulk Pr\(^{3+}\)/Yb\(^{3+}\)-co-doped ZLAG glasses. A sample with 0.5% Pr\(^{3+}\) and 10% Yb\(^{3+}\) exhibited an energy transfer efficiency of 92%, similar to the best results obtained in fluoride crystals (KY\(_3\)F\(_{10}\)) with the same doping.

Our work resulted in an effective quantum cutting process in glasses and transparent GC activated by RE ions. We found that 70SiO\(_2\)-30HfO\(_2\) GC and ZLAG glasses seem to provide suitable matrices for producing RE-activated films for a down-conversion process that is usable in a photovoltaic system. We are currently conducting studies of ZLAG GC to compare the evolution of the energy transfer efficiency from the parent glass to the GC as a function of ytterbium concentration.

This research was performed in the framework of the following research projects: Oxi-Solar, High Concentration Solar Cell–HCSC, European Union Cooperation in Science and Technology Action MP0702, and the Novel Silicon-Based Materials for Optoelectronics research project (2010–2013).

Author Information

Guillaume Alombert-Goget, Davor Ristic, Alessandro Chiasera, Stefano Varas and Maurizio Ferrari
Institute for Photonics and Nanotechnologies
Povo-Trento, Italy

Guillaume Alombert-Goget is a postdoctoral researcher at the Group for Characterization and Development of Materials for Photonics and Optoelectronics at the National Research Council’s Institute for Photonics and Nanotechnologies in Trento, Italy. In 2007, he was a postdoctoral researcher at the Laboratory of the Physical Chemistry of Luminescent Materials at the University of Lyon. He received his PhD in physics in 2007 from the University of Angers, France.

Giancarlo C. Righini
National Research Council, “Nello Carrara” Institute of Applied Physics
Florence, Italy

Belto Dieudonne and Brigitte Boulard
Laboratory of Oxides and Fluorides
University of Maine
Le Mans, France

References