OPTICAL ENHANCEMENT OF a-SiH_x SOLAR CELLS

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Infrared sensitivity of thin film solar cells is poor due to weak absorption by semiconductors near their band edges. The infrared absorption and short-circuit current of solar cells can, however, be significantly improved by "Optical Enhancement." We have used this process to increase the short-circuit current of a-SiH_x solar cells by more than 2.7 mA/cm^2 above comparable unenhanced cells having short-circuit currents of approximately 13 mA/cm^2. The techniques used to increase the short-circuit current are quite general and can be readily applied to other thin film solar cells.

The key to Optical Enhancement is breaking the plane-parallel symmetry of thin film solar cells in order to permit trapping of the incoming light within the semiconductor. This symmetry breaking is accomplished by texturing the semiconductor with structures having characteristic dimensions nearly equal to the wavelength of visible light within the semiconductor. This texture scatters incoming photons into optical modes which are trapped within the semiconductor increasing the path length for absorption. The maximum path length increase can in principle[1] be as much as a factor of $4n^2 \simeq 50$ where n is the index of refraction.

To produce the required texture, we have developed a new lithographic method called Natural Lithography[2]. Typically this lithographic method is used to fabricate microstructures having predetermined dimensions on the surface of a substrate. Materials forming the solar cell are deposited over the textured surface. Arrangement of materials forming the a-SiH_x cells is shown in the inset of Figure 1. To maximize enhancement effects, optical absorption in the reflector should be minimized. This has been done by utilizing a tuned reflector comprised of a metal such as Ag or Cu having good infrared reflectivity and an overcoating layer of transparent conductor (ITO). The transparent conductor layer decreases optical absorption in the textured reflector and also acts as a diffusion barrier preventing migration of the metal during deposition of a-SiH_x.

Effects of Optical Enhancement have been evaluated by comparing adjacent enhanced and unenhanced cells. Unenhanced cells contained a flat Cr layer in the reflector, while enhanced cells utilized textured Ag. Cells with flat Cr reflectors were chosen to represent the unenhanced case because optical absorption (in the Cr layer) limits any enhancement of current due to roughness in the as deposited a-SiH_x. A "flat" Ag reflector cannot be chosen as representative of the unenhanced case because light scattered by a small amount of residual roughness is not readily absorbed by the reflector and can produce a small enhancement. The roughness of many commercially available ITO films can lead to an enhancement ~1/3 that obtained here. Performance of adjacent enhanced and unenhanced cells was evaluated by measurement of collection efficiency[3] and also with a solar simulator. The principle effect of Optical Enhancement is to increase the short-circuit current with no degradation of voltage or fill factor. Representative open circuit voltages and fill factors are .84V and .6 respectively for the cells made in our laboratory. Magnitude of the current increase depends upon details of the texture. Optimal textures have roughness with a scale length of visible light in a-SiH_x and produce an increase of short-circuit current in excess of 2.7

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mA/cm^2. Normalized collection efficiencies for adjacent enhanced (textured Ag), unenhanced (flat Cr), and weakly enhanced (flat Ag) cells are shown in Figure 1. It is possible to compare normalized collection efficiencies because optical enhancement in no way impairs the anti-reflection coating. Effects of enhancement shown in Figure 1 are largest at longer wavelengths where light is weakly absorbed by the semiconductor. The percentage improvement in collection efficiency is shown in Figure 2 for another set of cells. It is seen that the onset of the enhancement effect has shifted to longer wavelength (as compared with Figure 1). This is due to the fact that the bandgap of cells shown in Figure 2 is smaller than those represented in Figure 1. It should be noted that the percentage improvement of collection efficiency at long wavelengths is a direct measure of the path length increase due to enhancement.

In summary, we have demonstrated that Optical Enhancement can significantly increase the short-circuit current of a-SiH_x cells. This feature can be readily incorporated into the different a-SiH_x cell designs being currently used and should yield 15-25% increases in efficiencies over cells not having any optical enhancement.

REFERENCES

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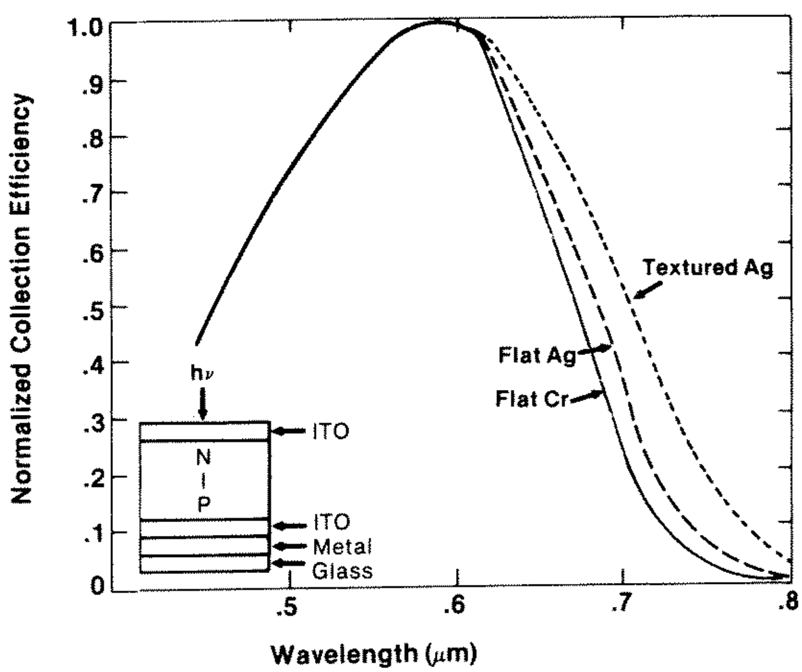

Figure 1. Normalized collection efficiency for enhanced (textured Ag), weakly enhanced (flat Ag) and unenhanced (flat Cr) cells.

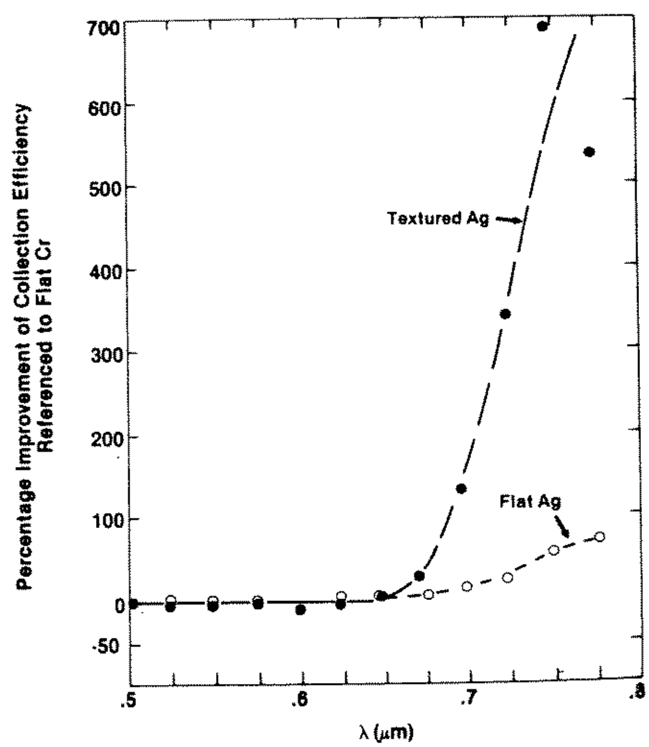

Figure 2. Percentage improvement of collection efficiency for a set of cells having a smaller bandgap than those shown in Figure 1.