

Probing photo-induced carrier recycling from doped-poly silicon with luminescence spectroscopy

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We present applications of luminescence spectroscopy to study transport behaviours of photo-induced carriers generated in films deposited on crystalline silicon (c-Si) solar cells, courtesy of distinct luminescence peaks emitted from these films at low temperatures. In particular, we investigate the carrier recycling from doped-poly and hydrogenated amorphous silicon (a-Si:H) films into c-Si substrates. We find that there is a strong carrier injection from these films into the substrate when no oxide barrier is present between the films and the substrate. However, the presence of an ultrathin layer of oxide effectively blocks the transport of the excess carriers from the films into the substrate, suggesting that there is no carrier recycling from these films in practical passivating-contact solar cells.

Carrier recycling from a-Si:H layers

Fig.1 show direct evidences of photo-induced carriers injected from a-Si:H films into c-Si substrates, as observed on photoluminescence (PL) spectra. A typical low-temperature PL spectrum captured from a c-Si sample capped with an a-Si:H film consists of two main peaks - a sharp peak ~ 1130 nm and a very broad peak ~ 900 - 1000 nm. The former is emitted from the c-Si substrate whereas the latter is emitted from the a-Si:H film.

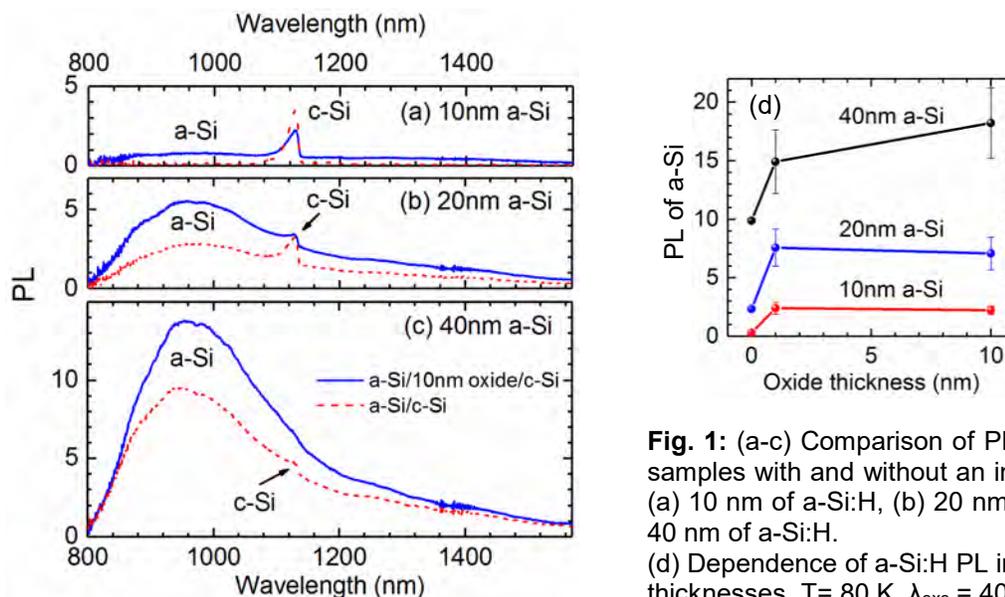


Fig. 1: (a-c) Comparison of PL spectra between samples with and without an inter-layer of oxide: (a) 10 nm of a-Si:H, (b) 20 nm of a-Si:H, and (c) 40 nm of a-Si:H. (d) Dependence of a-Si:H PL intensities on oxide thicknesses. $T = 80$ K, $\lambda_{exc} = 405$ nm.

In Fig. 1a (10-nm layer of a-Si:H), the a-Si:H/c-Si sample does not show any emission from the a-Si:H film. This suggests that a significant number of excess carriers generated in the film have moved into the substrate in the case of a-Si:H/c-Si, but they are blocked by a 10-nm layer of oxide. Figs. 1b and 1c continue showing spectra with thicker a-Si:H films, 20 nm and 40 nm, respectively. From these spectra, the same conclusion can be obtained although a strong emission from a-Si:H films for a-Si:H/c-Si samples is observed. With thicker a-Si:H films, the excess carriers generated in the films have to travel longer distances before reaching the interface, and thus reducing the number of carriers injected into

the substrate. When the film thickness is increased up to 40 nm, the excitation light is mainly absorbed inside the a-Si:H layer. Thus, we hardly detect any PL signal from the substrate (Fig. 1c, solid blue curve) in the a-Si:H/oxide/c-Si sample. However, when the oxide inter-layer is absent, the carriers still flow into the substrate, giving rise to a small c-Si peak (Fig. 1c, broken red curve).

Fig. 1d shows dependencies of a-Si:H PL intensities on oxide thicknesses. Consistently across various a-Si:H thicknesses, the PL intensity is the same for both 10-nm and 1-nm oxide thicknesses. Meanwhile, the PL intensity of the sample without the oxide layer (zero thickness) is reduced significantly. These results demonstrate that the 1-nm layer of oxide can block the transport of most of photo-generated carriers from the amorphous film into the c-Si substrate.

Carrier recycling from doped-poly layers

We apply the same concept presented above for a-Si:H films to investigate the carrier recycling from doped-poly films in passivating-contact solar cells. First, we report PL emissions from doped-poly layers. Fig. 2a shows PL spectra from an n⁺ poly/1.3-nm oxide/c-Si sample. The doped-poly layer is about 50-nm thick. The spectrum with a 405-nm excitation light contains a very broad peak at wavelengths longer than the emission from the c-Si substrate. With increasing excitation wavelengths, the laser light penetrates more deeply into the substrate and the PL spectrum contains mainly the emission from c-Si (Fig. 2a, broken red curve). Thus, the difference spectrum between the two curves represents the emission from the near-surface region. Moreover, the intensity of this broad peak increases with increasing thicknesses of doped-poly films (Fig. 2b), confirming that the emission at long wavelengths originates from the doped-poly layer. Moreover, Fig. 2c shows intensity dependencies of doped-poly emissions on oxide thicknesses. In this figure, a 1.3-nm layer of oxide is sufficient to prevent the photo-induced carriers in the doped-poly layer from moving into the substrate.

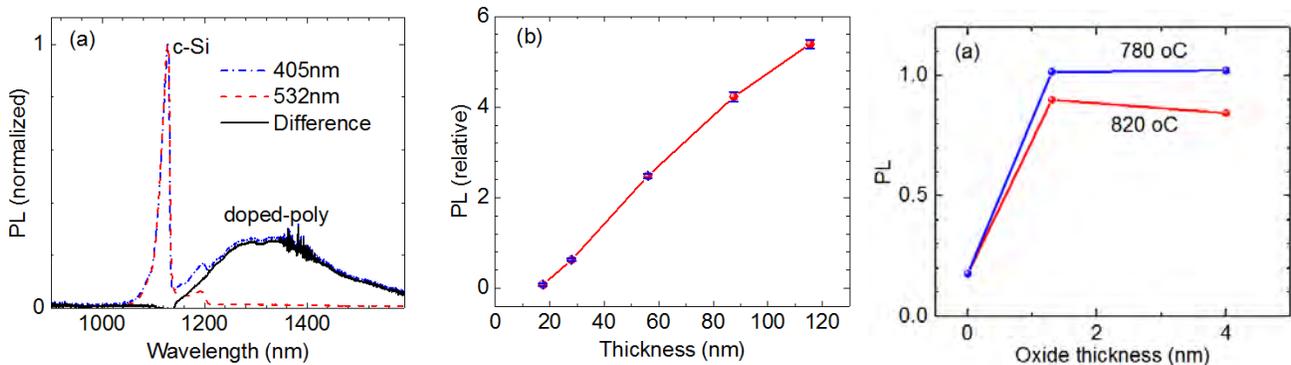


Fig. 2: (a) PL spectra from an n⁺ poly/1.3-nm oxide/c-Si structure with 532-nm and 405-nm excitation wavelengths and the difference spectrum between the two spectra, at 80K. (b) Dependencies of doped-poly PL intensities on poly thicknesses and (c) oxide thicknesses. Temperatures in Fig. 2c are diffusion temperatures.

The final presentation will provide an in-depth underlying physics of this technique and demonstrate a wide range of applications in c-Si photovoltaics. This contactless, non-destructive PL-based technique could be a powerful tool to characterize transport properties of free carriers in deposited films for c-Si solar cells.