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Characterization of electronic transport properties of semiconductor films during plasma processing

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The electronic transport properties of hydrogenated amorphous silicon (a-Si:H) film during plasma enhanced chemical vapor deposition (PECVD) have been studied. We find that during PECVD, carrier transport is governed by plasma induced defects located near the surface (< 20nm). On the other hand, trapped carriers are distributed not only in the defect rich surface layer but also in the bulk layer. The origin for carrier trapping is recognized to be the band tail states, rather than the deep level defect states, associated Si dangling bonds.

Carrier transport is an key factor that determines the performances of semiconductor devices such as solar cells and transistors. Particularly, in those devices including amorphous materials of semiconductors, the transport is limited by carrier trapping, related to various defects and impurities. So far, the transport and trapping phenomena have been studied mainly for as-grown films or devices at room temperature. However, those have not been studied under plasma processing, even though the defects are usually created under plasma processing. Here, we study the electronic transport properties of a-Si:H film during PECVD [1].

We measured the photo and trap-induced currents in a-Si:H film growing on a glass substrate during PECVD [2]. These currents are measured under pump (532 nm, 0.4mW) and probe (1432 nm, 500mW) light. The pump generated photoexcited carriers and filled the traps, whereas the probe was used to emit trapped carriers to the conduction band. These carriers were then collected by the interdigitated contacts on the glass substrates.

The measured optoelectronic properties of a-Si:H films during PECVD are shown in Fig. 1. It is confirmed that the thickness, d, is nicely proportional to the growth time, t, while the optical constants stay nearly constant. The growth rate and optical constants are 0.17 nm/s, E_g = 1.61 eV, n = 4.6, and k = 0.45 at 532 nm. Figure 1 (c) shows the time evolution of photo and trap currents, I_p and I_t. Interestingly, both currents remain nearly zero at an initial stage of growth (t < 120 s, i.e., d < 20 nm) and then increase gradually with t. The photoconductivity, σ_p, is improved with t, as shown in Fig. 2(d). Such time evolutions suggest that a defect-rich surface layer is formed initially, and then the bulk layer is grown underneath it. This defect-rich surface layer is evaluated to be less than 20 nm. The time evolution of trapped carrier density, n_t/n_v, determined from I_t/I_p [3] is shown in Fig. 2(d). We find that n_t/n_v stays roughly constant as the film grows with t. The result indicates that the trapped carriers are distributed homogeneously along the direction of growth. The absolute density of trapped carriers is the order of 10^{17} cm^{-3} for the device grade intrinsic a-Si:H [2]. In the talk, the correlation between transport properties and device performances will be also presented.

[1] S. Nunomura, I. Sakata, M. Kondo, *Appl. Phys. Express*. **6** (2013) 126201.

[2] S. Nunomura and I. Sakata, *AIP Adv.* **4** (2014) 097110.

[3] S. Nunomura, X. Che, and S. R. Forrest, *Adv. Mater*. **26** (2014) 7555.

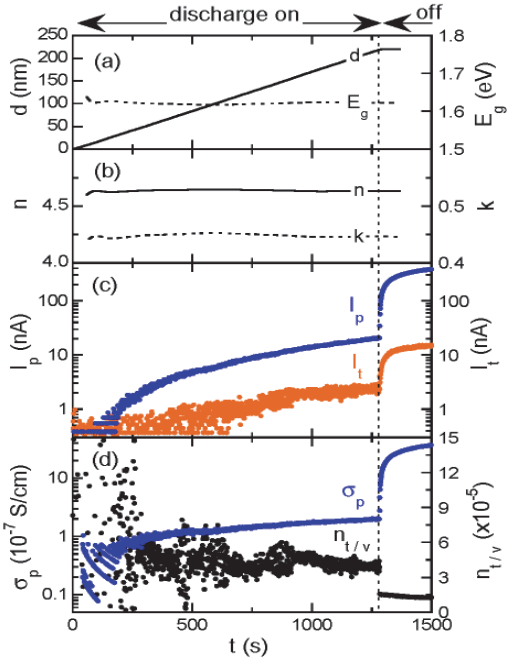

Fig. 1. Opt-electrical properties of a-Si:H film during PECVD. (a) Thickness, d, and optical bandgap, E_g. (b) refractive index, n, and extinction coefficient, k. (c) photo and trap currents, I_p and I_t. (d) photoconductivity, σ_p, and the normalized trapped carrier density, n_t/n_v,