Experiment of Drifting Mobilities of Holes and Electrons in Stabilized a-Se Film

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The electrical properties of stabilized amorphous selenium typical of the material used in direct conversion x-ray imaging devices are reported. Carrier mobility was measured using time-of-flight (TOF) measurements to investigate the transport properties of holes and electrons in stabilized a-Se film. A laser beam with pulse duration of 5 ns and wavelength of 350 nm was illuminated on the surface of a-Se with thickness of 400 μm. The photo induced signals of a-Se film as a function of time were measured. The measured transit times of hole and electron were about 8.73 μs and 229.17 μs, respectively. The hole and electron drift mobilities decreases with increase of electric field up to 4 V/μm. Above 4 V/μm, the measured drift mobilities exhibited no observable dependence with respect to electric field. The experimental results showed that the hole and electron drifting mobility were 0.04584 $cm^2V^{-1}s^{-1}$ and 0.00174 $cm^2V^{-1}s^{-1}$ at 10 V/μm.

Keywords : Amorphous selenium, Mobility, Time of Flight, Digital Radiography

1. INTRODUCTION

Recently developed direct conversion flat panel x-ray image detectors provide not only potentially superior images but also enable a simple and convenient means of achieving digital radiography. The present flat panel sensors utilize stabilized amorphous selenium (a-Se) as a x-ray photoconductor to convert x-ray photons to collectable charge carriers[1-4]. A-Se is endowed with a number of remarkable physical properties, making it an attractive material for a wide variety of electronic device applications. It has low dark current and good linearity compared to other photoconductor materials. The a-Se layer that is currently being studied for its use as an x-ray photoconductor is not pure a-Se but rather a-Se doped with 0.2-0.5% As and 10-30 ppm Cl, also known as stabilized a-Se. The suitability of the stabilized a-Se is largely determined by its charge on generating, transporting and trapping properties[5].

Although hole and electron transport in a-Se is well documented, mobilities and lifetimes of hole and electron in a-Se:0.3% As photoconductors that have been used in current x-ray detectors are not clear[6]. In this paper, time-of-flight (TOF) of drifting electrons and holes in stabilized a-Se film was used to investigate electron and hole drift mobility[7,8].

2. EXPERIMENTAL

2.1 Time of flight (TOF) technique

The starting materials were prepared by adding 0.3 wt% arsenic and 30 ppm clorine to selenium pallet of 99.999% purity (Nippon Rare Metal Co., Japan) for improving the conducting and thermal properties [6]. The stabilized a-Se layer of 400 μm thickness was prepared onto heated indium tin oxide (ITO) substrate by thermal evaporation method. A semitransparent gold layer was deposited onto upper surface of the a-Se layer as a upper electrode.

Figure 1 shows the schematic diagram illustrating the principle of TOF measurement. A voltage was applied across the a-Se layer sandwiched between Au electrode and ITO electrode for collecting charges. The applied bias (V) appeared across the thickness of a-Se layer since the external resistance is much less than the a-Se

resistance. A short light pulse of 5nm from laser light source (350 nm) was employed to photogenerate free charges. The transit across a-Se layer produced a measurable current in the external circuit. The transient voltage, R_L, was monitored on an oscilloscope (LeCroy LC 334AM, USA) as a photo response signal.

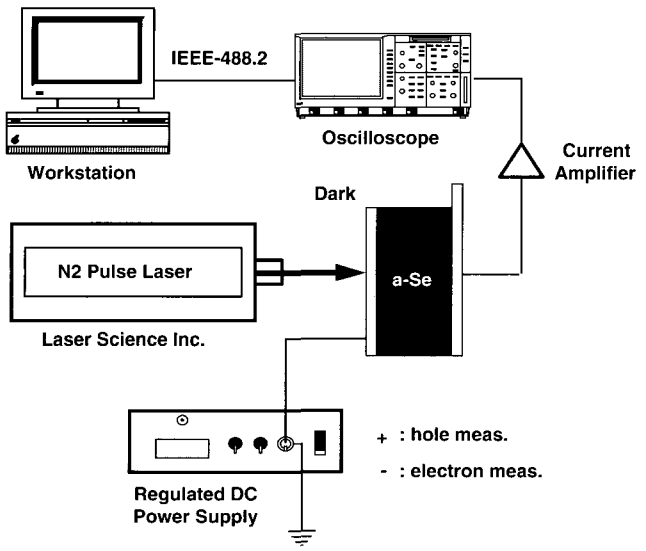

Fig. 1. The schematic diagram for TOF measurement.

2.2 Transit time

A time-of-flight technique was used to measure the transit time and mobility of hole and electron [11]. To time resolve the current transient, the duration, 5ns of laser pulse must be short compared to the shortest measurable transit time and the absorption coefficient of a-Se layer must be sufficiently large so that the light is absorbed in a narrow region close to the top electrode. The transit voltage across R is monitored on an oscilloscope. The signal across the load resistance depends on the *RC* time constant of the circuit, *RLC*, where $C = A/L$ is the capacitance of the a-Se layer with *A*, the area of the electrode and L, the thickness of the a-Se layer.

Charge transport property is based on *Schubweg* limitation, which means that $\mu_{\tau E}$, the carrier *Schubweg*. In this case, lifetime (τ) is bigger than transit time (t_T), therefore given by:

$$\tau = t_T$$

$$Schubweg \text{ distance} = \mu\tau E >> L \qquad (1)$$

Where E is the electric field in the regions of the a-Se layer that have received the maximum exposure.

The transport process must occur in the absence of deep trapping and within a time commensurate with process development requirements. *Schubweg* distance is defined as the distance moved by an electron and hole within a-Se layer before being trapped.

2.3 Drif mobility

Drift is, by definition, charged particle motion in response to an applied electric field. Mobility is obviously a parameter in characterizing hole and electron transport due to drift. When an electric field is applied across a-Se, the carriers start moving, producing a current. The positively charged holes move with the electric field, whereas the negatively charged electrons move against the electric field.

Drift mobility is given by:

$$\mu = \frac{L}{t_T E} = \frac{L^2}{t_T V}[cm^2 / v \cdot s]$$

$$V = E \cdot L \quad : \text{applied bias} \qquad (2)$$

The drift mobility of charge carrier in the photoconductor is affected by the temperature and given by:

$$\mu(E,T) = \mu_0 \exp(-\frac{\varepsilon_o}{k_B T}) \exp(\frac{\beta E^{\frac{1}{2}}}{K_B T}) \qquad (3)$$

where ε_0 : activation energy at zero bias
k_B : Boltzmann constants
β : reduction parameter

The a-Se film revealed no temperature-dependence in this study, therefore temperature-dependence was not a factor in analysis.

3. RESULTS AND DISCUSSION

3.1 Transit time

The transient current TOF signals for a-Se layer (400 μm) are shown in Fig. 2 and Fig. 3. The transient TOF waveforms were taken after the application of 10 V/μm across the a-Se layer. The transient indicates that the electric field remains uniform across the a-Se film layer, suggesting the presence of hole and electron trapping within the a-Se layer. The transit time becomes dependent on applied electric field to raise charge collection as a theoretical anticipation value.

The transit times of hole and electron are 8.72 and 229.2 μs, respectively, at a voltage bias of 10 V/μm. TOF transient photocurrents exhibited similar behaviors with those in an a-$Se_{0.966}Te_{0.034}$ alloy photoreceptor film reported by J. A. Rowland and S. O. Kasap previously [3].

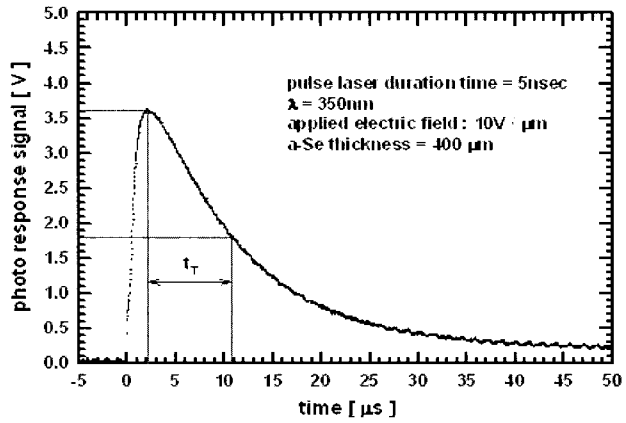

Fig. 2. Photo response signal of hole.

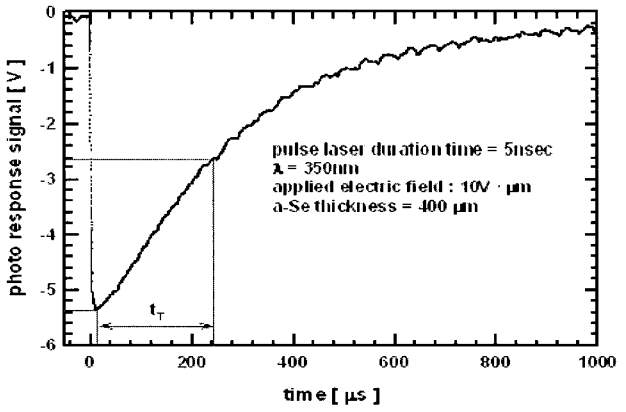

Fig. 3. Photo response signal of electron.

Table 1 shows the transit times of hole and electron as a function of electric field. As shown in Table, The transit times of hole and electron are inversely proportional to the applied electric field up to 10 V/μm.

Table 1. Transit time of hole and electron as a function of electric field.

Electric Field [V/μm]	Transit time [μs]	
	Hole	Electron
4	24.9688	565.1245
5	19.0840	450.8741
6	16.2088	370.5562
7	13.8562	337.2540
8	10.9794	299.5000
9	9.9339	247.5556
10	8.7267	229.1730

3.2 Mobility

The relationship between charge-carrier mobility μ and the measured transit time t_T is given by:

$$\mu t_T E = L$$
$$\mu = \frac{L}{t_T E} = \frac{L^2}{t_T V} \quad (4)$$

The drift mobility of hole and electron exhibited observable field dependence up to 4 V/μm, as shown in Fig. 4 and 5.

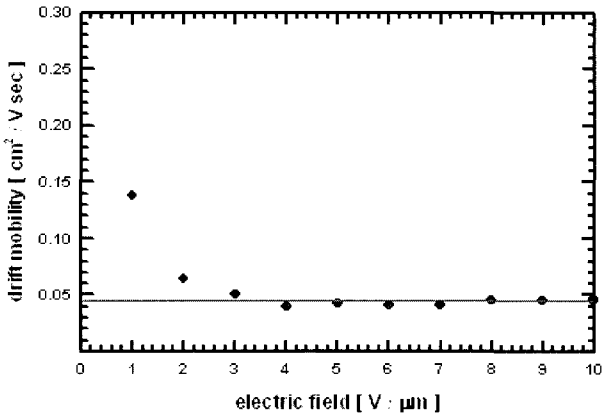

Fig. 4. The drift mobility of hole as a function of applied electric field.

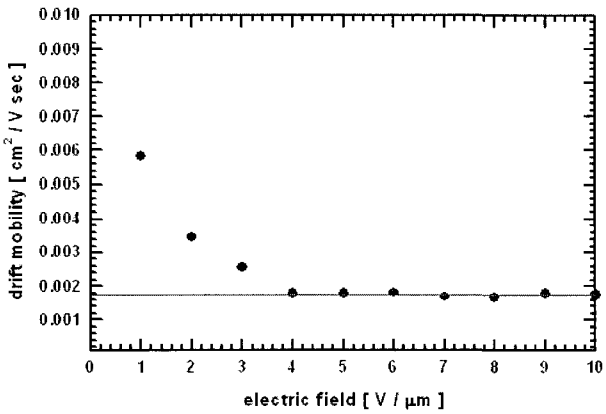

Fig. 5. The drift mobility of electron as a function of applied electric field.

The drift mobility of hole and electron at 10 V/μm are 0.04584 and 0.00174 $cm^2V^{-1}s^{-1}$, respectively. The obtained drift mobility of hole is somewhat different from the value of 0.13 $cm^2V^{-1}s^{-1}$, reported previously by Kasap et al[4]. After careful analysis, this apparent difference in hole mobility seems to be due to both the temperature dependence and doping quantity of stabilized a-Se film.

4. CONCLUSION

The drift mobility of electron and hole was measured in stabilized a-Se using a time of flight technique. We have demonstrated that it is possible to measure the x-ray sensitivity of stabilized a-Se detector. The transit times of the hole and electron are strongly dependent to the electric field applied for collecting the carriers. The measured transit times of the hole and electron were about 229.17 μs and about 8.73 μs at 10 V/μm, respectively. The drift mobility of hole and electron in stabilized a-Se layer with 0.3% As and 30ppm ppm Cl was 0.04584 and 0.00174 $cm^2V^{-1}s^{-1}$ at 10 V/μm.

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