KIEE International Transactions on EA, Vol. 4-C, No. 4, pp. 185~189, 2004 **185**

Relationship between Secondary Electron Emissions and Film Thickness of Hydrogenated Amorphous Silicon

Sung-Chae Yang*, Byung-Yoon Chu, Seok-Cheol Ko** and Byoung-Sung Han****

Abstract: The temporal variation of a secondary electron emission coefficient (γ coefficient) of hydrogenated amorphous silicon (a-Si:H) was investigated in a dc silane plasma. Estimated γ coefficients have a value of 2.73×10^{-2} on the pure aluminum electrode and 1.5×10^{-3} after 2 hours deposition of –Si:H thin films on a cathode. It showed an abrupt decrease for about 30 minutes before saturation. The variation of the γ coefficient was estimated as a function of the thin film thickness, and the film thickness was about 80 nm after 30 minutes deposition time. These results are compared with the results of a computer simulation for ion penetration into a cathode.

Keywords: hydrogenated amorphous silicon (a-Si:H), Paschen's law, secondary electron emission coefficient (γ coefficient), SiH* optical emission spectroscopy (OES)

1. Introduction

The plasma enhanced chemical vapor deposition (PECVD) method has been widely used in the preparation of functional thin films such as hydrogenated amorphous silicon (a-Si:H) and hydrogenated amorphous carbon (a-C:H). Recently, various experimental and numerical studies concerning variation of discharge characteristics have focused on variation of a secondary electron emission coefficient (γ coefficient) [1-7].

The temporal variation of discharge characteristics normally occurs in the early stages of the deposition process of thin films such as a-Si:H and a-C:H. In this study, attention has been paid mainly to the effect of the temporal variation for the γ coefficient. Therefore, in order to clarify the mechanism of the temporal variation of discharge characteristics, we estimated the γ coefficient of a-Si:H thin films deposited during early deposition time by breakdown characteristics (Paschen's Law) in a dc silane plasma.

However, it is noted that the variation of the γ coefficient should be measured as a function of not only deposition times but also thin film thickness. Regrettably, a substantial thin film thickness in the early deposition time cannot be measured exactly because the film thickness of this region is not more than ~ nm. Therefore, we estimated the temporal variation of SiH* optical emission (414.2 nm), which is proportional to the a-Si:H deposition rate [8]. Using these data, the thickness of a-Si:H thin films for all of the deposition times can be estimated. From the above investigation, the variation of γ coefficient is obtained as a function of thin film thickness.

Finally, in order to enhance the above result, it was compared with the outcome of a computer simulation using the TRIM code (Transport of Ions in Matter of IBM makes).

2. Experimental Apparatus

A schematic diagram of the experimental apparatus used in this study is shown in Fig. 1. The cylindrical vacuum chamber was 32 cm in diameter and 230 cm in length, and made of stainless steel (SUS304). Two parallel-plate electrodes composed of aluminum were 5 cm in height, 7 cm in length and 5 cm in gap length. It was also surrounded with ceramic covers. In this study, SiH_4 (10%)/Ar gas was used for a-Si:H thin film deposition on the surface of the cathode, and pure Ar gas was used for measurement of the breakdown characteristics.

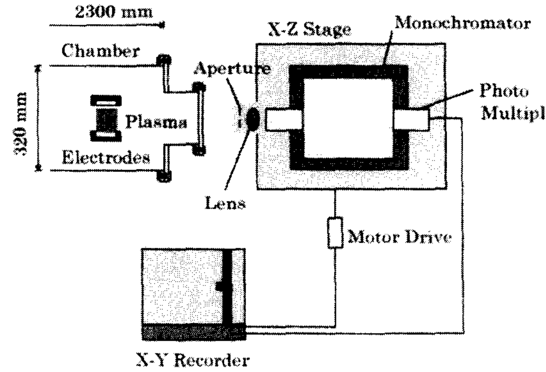


Fig. 1 Schematic diagram of experimental apparatus

---

* Division of Electronics and Information, Chonbuk National University, Korea (yangsc@chonbuk.ac.kr)

** Division of Electronics and Information, Chonbuk National University, Korea

Received May 18, 2004 ; Accepted May 30, 2004

The spatial profiles of one-dimensional optical emission spectroscopy (OES) in the discharge region were analyzed with a 250 mm monochromator (dispersion of 2 nm/mm) mounted on a movable stage. The spatial resolution in the observation space was 1.5 mm (horizontal) × 6 mm (vertical). The spatially resolved plasma emission was detected by a photo-multiplier attached to the exit slit of the monochromator and then recorded with an X-Y recorder.

3. Experimental Results and Discussion

To estimate the γ coefficient for a-Si:H thin film deposited on the electrode, we measured breakdown characteristics for various deposition times, i.e. thin film thickness. The minimum value of the breakdown voltage (V_{smin}) and pressure × gap length (Pd_{min}) for the deposition times were obtained experimentally via Paschen's curves in pure Ar gas. From these experimental results, V_{smin} and Pd_{min} for glow discharge were obtained as shown in Fig. 2. Fig. 2 depicts the temporal variation of V_{smin} and Pd_{min} for a-Si:H thin film under conditions for pressure P = 0.12 Torr and applied voltage V = 600 V. From this Fig., it is found that both V_{smin} and Pd_{min} increase with deposition time, and after that the V_{smin} slightly increases and Pd_{min} is saturated.

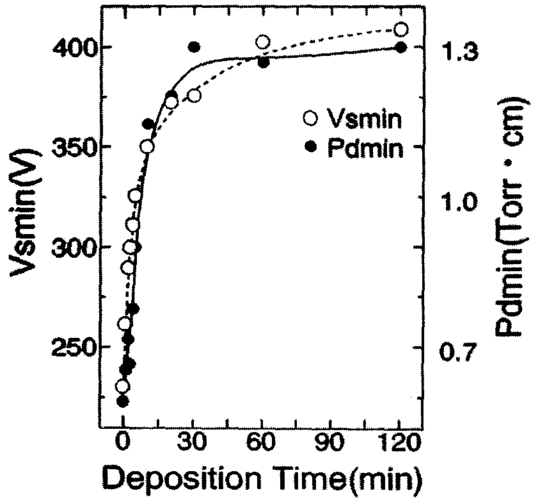


Fig. 2 Temporal variation of V_{smin} and Pd_{min} measured under the conditions for pressure P = 0.12 Torr and applied voltage V = 600 V.

Next, using the above results, we estimated the γ coefficient of a-Si:H for the deposition time from Paschen's law. Paschen's law is described as follows:

$$V_s = \frac{B \cdot Pd}{\ln(A \cdot Pd)} - \ln \ln(1 + \frac{1}{\gamma}) \qquad (1)$$

From the above equation, the minimum breakdown conditions are provided as follows:

$$V_{s\min} = \frac{B \cdot 2.718}{A} \ln(1 + \frac{1}{\gamma}) \qquad (2)$$

$$Pd_{\min} = \frac{V_{s\min}}{B} \qquad (3)$$

Here, A and B are constant for each gas, e.g. A=13.6, B=235 in Ar gas [9].

As V_{smin} and Pd_{min} depend on the γ coefficient, we can calculate the γ coefficient by using the measured values of V_{smin} and Pd_{min} and equations (2) and (3). Here, we utilized the fact that the constant value of A was 13.6 and B was determined by equation (3).

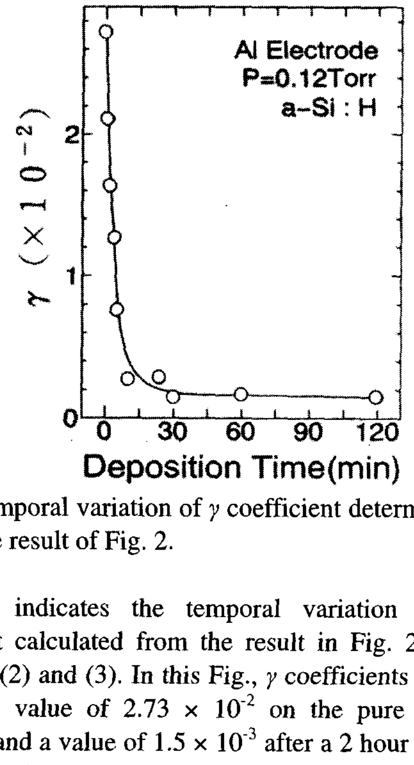


Fig. 3 Temporal variation of γ coefficient determined from the result of Fig. 2.

Fig. 3 indicates the temporal variation of the γ coefficient calculated from the result in Fig. 2 by using equations (2) and (3). In this Fig., γ coefficients are shown to have a value of 2.73 × 10^{-2} on the pure aluminum electrode and a value of 1.5 × 10^{-3} after a 2 hour deposition of a-Si:H thin films. Under the present experimental conditions, it was determined that the value of γ coefficient was reduced to about one-tenth after 2 hours of deposition.

From the above results, it was found that the calculated values of the γ coefficient abruptly decrease and saturate at about 30 minutes of deposition time. This result also suggests that the electrical property of the thin film changes from the virgin aluminum electrode to complete a-Si:H at about 30 minute of deposition time. However, the thin film prior to 30 minutes of deposition shows the mixed property of electrode (aluminum) and the deposited film (a-Si:H) as the transition layer because the film thickness is very thin.

In this study, a substantial film thickness in the vicinity of 30 minutes deposition cannot be measured because the film thickness is very thin. Therefore, to estimate the γ coefficient as a function of the film thickness, we utilized the fact that the deposition rate of a-Si:H is proportional to optical emission intensity from SiH* (414.2 nm) [8].

Fig. 4 demonstrates the spatial distribution of SiH* emission intensity, 414.2 nm, in 0.12 Torr and 600 V. From this Fig. we find the following common features: 1) the emission profile is composed of two peaks, i.e., one at the negative glow region (first peak) and another at the cathode sheath region (second peak), 2) the width of the cathode sheath region is about 8 mm, which is from the cathode surface to the end of the first peak.

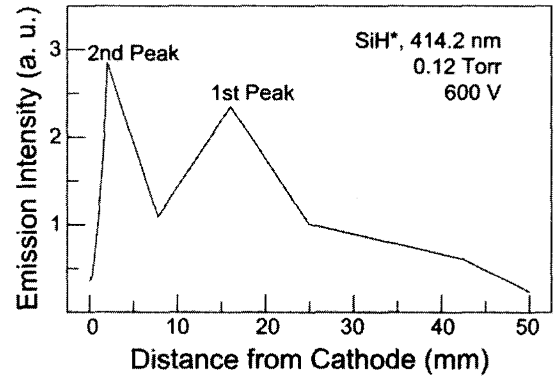


Fig. 4 Spatial distribution of SiH* emission intensity.

Figs 5 and 6 show the temporal variation in profiles of SiH* emission intensity of the first peak and the second peak, respectively. In these Fig.s, it is established that the emission intensity from SiH* abruptly decreases until about 30 minutes and slightly decreases after that time. This result agrees well with the temporal variation of γ coefficients, as shown in Fig. 3.

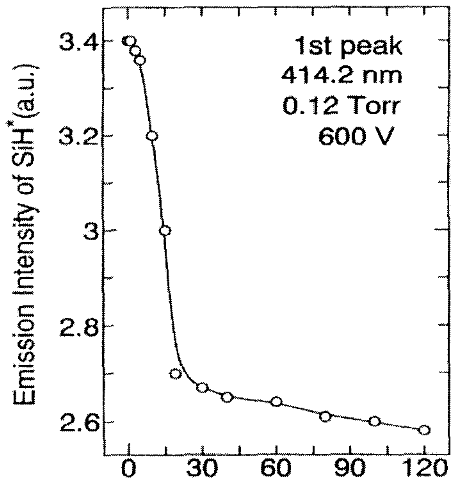


Fig. 5 Temporal variation of SiH* (414.2 nm) emission intensity at the peak in the negative glow region.

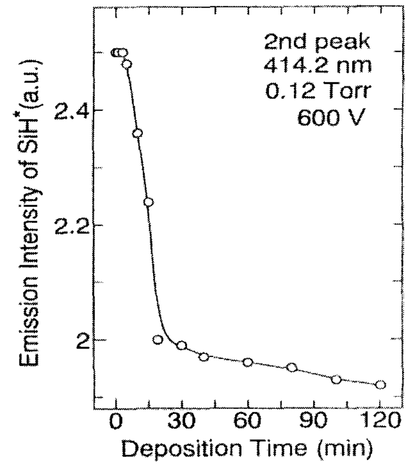


Fig. 6 Temporal variation of SiH* (414.2 nm) emission intensity at the peak in cathode sheath region.

From the above result, if we know the thin film thickness for one of the several deposition times, we can estimate the γ coefficient as a function of the thin film thickness by using both the film thickness and the results obtained from Figs. 5 and 6. Therefore, we estimated the measurable thin film thickness after a lengthy deposition time. Consequently, it was obtained that the film thickness for 60 minutes and 120 minutes deposition were about 150 nm and 280 nm, respectively.

Using the results in Fig. 6, we determined thin film thickness from the experimental result that the film thickness at 60 minutes deposition was about 150 nm, and then it was obtained that the deposition rate at starting deposition time was 3 nm/min. As the deposition rate decreased with SiH* emission intensity, those at 30, 60 and 120 minutes deposition time were estimated as 2.35, 2.32 and 2.27 nm/min, respectively.

From the above investigation, the γ coefficient as a function of thin film thickness could be obtained, as shown in Fig. 7. In this Fig., it is found that the γ coefficient abruptly decreases and is saturated over the film thickness of about 80 nm. If the lattice constant of this film is 5.43 Å, which is the same as crystal Si, it is considered that the 150 layers are prepared on the cathode surface after 30 minutes of deposition. It is also suggested that the electrical property of the thin film changes from the virgin aluminum electrode to the complete deposited film (a-Si:H) with about 80 nm in thickness.

Finally, we compared the above results with those of a computer simulation using a TRIM (Transport of Ions in Matter of IBM make) code. The result of the TRIM is shown in Fig. 8. It was obtained under the conditions for Ar ion injection with the incident energy of E_i = 600 eV into silicon thin films with several film densities, ρ .

From this Fig., it is found that 600 eV Ar ions penetrate into 80 nm depth of Si thin films when the density is assumed to be 1.8 g/cm^3. This result means that the density of the thin films prepared in this study is about 1.8 g/cm^3 and that it is smaller than that of crystalline Si, 2.33 g/cm^3.

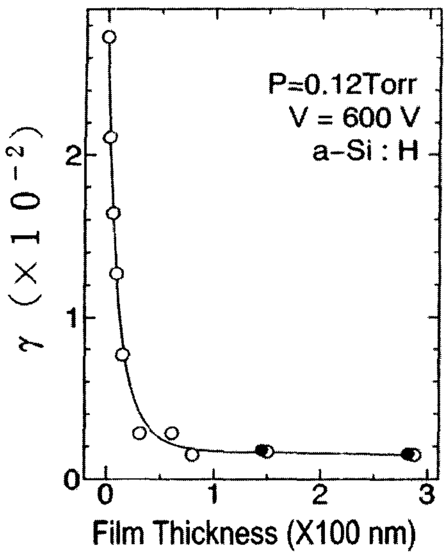


Fig. 7 Variation of γ coefficient as a function of a-Si:H thin film thickness determined by using the result of Fig. 5 and the thin film thickness actually measured. Calculated points and measured points are shown by open circles, ○, and closed circles, ●, respectively.

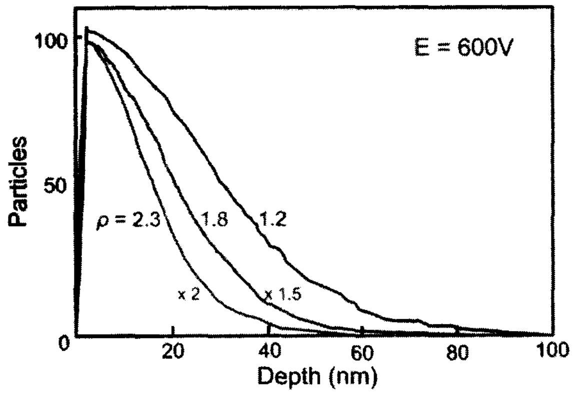


Fig. 8 Result of computer simulation using the TRIM code under the condition for Ar ion taken incidence energy E = 600 eV into a-Si:H thin film with various density, ρ .

4. Conclusion

To estimate the γ coefficients for a-Si:H thin films deposited on electrodes, the temporal variation of V_{smin} and Pd_{min} was measured. These were estimated to be 2.73×10^{-2} on the pure electron in aluminum and 1.5×10^{-3} at 2 hours deposition of a-Si:H thin films. In present experimental conditions, the value of γ coefficient was reduced to about one-tenth after 2 hours of deposition. Furthermore, it was found that the calculated value of the γ coefficient abruptly decreased and was saturated at about 30 minutes of deposition time.

Conversely, the temporal variation of SiH* emission intensity was investigated at the peak in the negative glow region (first peak) and at another peak in the cathode sheath region (second peak). Additionally, we found that the film thickness for 60 minutes and 120 minutes of deposition time were about 150 nm and 280 nm, respectively, under the present conditions. From these results, the thickness of a-Si:H thin film could be obtained as a function of deposition time.

From these results, the γ coefficient as a function of thin film thickness was obtained. Consequently, we found that the electrical property of thin film changed from the virgin aluminum electrode to the complete a-Si:H at about 80 nm in thickness. Then we established that the deposition rates at 0, 30, 60 and 120 minutes deposition time were 3.0, 2.35, 2.32 and 2.27 nm/min, respectively. Finally, from the result of the TRIM code, the density of a-Si:H thin films was estimated to be about 1.8 g/cm^3, under the present conditions.

Acknowledgements

This work was supported in part by research funds from Chonbuk National University and by KESRI (R-2003-B-072), which is funded by MOCIE (Ministry of Commerce, Industry and Energy).

References

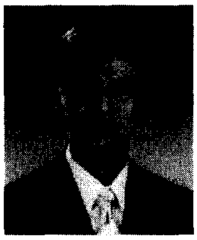
[1] O. Sahni and C. Lanza, "Influence of the secondary electron emission coefficient of argon on Paschen breakdown curves in ac plasma panels for neon + 0.1 % argon mixture", J. Appl. Phys., vol. 47, pp. 5107-5108, 1976.

[2] G. Auday, Ph. Guillot, J. Galy and H. Brunet, "Experimental study of the effective secondary emission coefficient for rare gases and copper electrodes", J. Appl. Phys., vol. 83, pp. 5917-5921, 1998.

[3] O. B. Postel and M. Cappelli, "Vacuum emission and breakdown characteristics of a planar He-Xe microdischarge", Appl. Phys. Lett., vol. 76, pp. 544-546, 2000.

[4] M. Hirata et. al., "A novel electrostatic ion-energy spectrometer by the use of a proposed "self-collection" method for secondary-electron emission from a metal collector", Rev. Sci. Instrum., vol. 74, pp. 1913-1916,

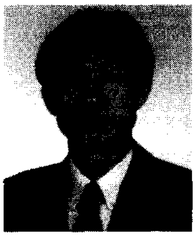
2003.
[5] J. Y. Lim et. al., "Work function of MgO single crystals from ion-induced secondary electron emission coefficient", J. Appl. Phys., vol. 94, pp. 764-769, 2003.
[6] Y. H. Cheng, H. Kupfer and F. Richter, "Influence of duty cycle on the structure and secondary electron emission properties of MgO films deposited by pulsed mid-frequency magnetron sputtering", J. Appl. Phys., vol. 94, pp. 3624-3628, 2003.
[7] Y. Sosov and C. E. Theodosiou, "Determination of electric field-dependent effective secondary emission coefficients for He/Xe ions on brass", J. Appl. Phys., vol. 95, pp. 4385-4388, 2004.
[8] M. Takai, T. Nishimoto, M. Kondo and A. Matsuda, "Anomalous behavior of electron temperature in silane glow discharge plasmas", Thin Solid Films, vol. 390, pp. 83-87, 2001.
[9] A.von Engel, "IONIZED GASES", Oxford University Press, p.151, 1965.



Sung-Chae Yang
He was born in Busan, Korea, in 1966. He received his M.S. and Ph.D. degrees in Electrical Engineering and Computer Science from Nagasaki University, Japan, in 1994 and 1997, respectively. His research interests include applications of plasma science & technology i.e., nanocrystalline and amorphous silicon thin films, silicon nano particles and applications of carbon fullerenes.

Byung-Yoon Chu
He received his B.S. degree in Division Electronic & Information Engineering (electrical engineering) from Chonbuk National University, Korea in 2001. He is currently enrolled in a Master's Course in electrical engineering at Chonbuk National University, Korea.

Seok-Cheol Ko
He received his B.S. and M.S. degrees in Electrical Engineering from Chonuk National University. In 2002, he joined the School of Electrical Engineering of Chonbuk National University, where he is currently working towards his Ph.D. degree in the field of nanoelectronics technology and superconducting transistors with low power devices and their applications.



Byoung-Sung Han
He was born in Chonbuk, Korea, on December 22, 1951. He received his Ph.D. degree from Pasteur University. He was a researcher of the CNRS in France in 1988. He is presently a Professor in the Department of Electrical Engineering at Chonbuk National University.