Journal of Information Display, vol. 4, no. 1, 2003

Alternating Magnetic Field Crystallization of Amorphous Si Films

K.H. Kang, S.H. Park, S. J. Lee, S. E. Nam, and H.-J. Kim

Abstract

We investigate the solid phase crystallization of amorphous Si films on glass substrates under alternating magnetic field induction. The kinetics of crystallization are found to be greatly enhanced by alternating magnetic field. While complete crystallization takes heat treatment of more than 14 hours at 570 ℃, it can be reduced by applying the megnetic field to 20 minutes. It is assumed that the enhancement of crystallization is associated with an electromotive force voltage generated by alternating magnetic field. This electric field applied in the amorphous Si may possibly be the reason for acceleration of the atomic mobility of crystallization through the modification of atomic potentials

Keywords : *alternating magnetic field crystallization* (AMFC)

1. Introduction

In recent years, formation of device-quality poly-Si films on glass substrate has been the subject of intensive research as it is a key process in advanced flat panel displays, such as poly-Si TFT LCDs and OLEDs. A typical method for obtaining poly-Si films is the solid phase crystallization (SPC) of amorphous Si [1-3]. However, due to the high process temperature and long process time it is difficult to employ the SPC process on thermally susceptible glass substrate. Recently, metal induced crystallization has been proposed as a means to lower crystallization temperature. However, significant incorporation of metal impurities into Si films degrades the electrical characteristics of thin film transistors [4-7]. There fore in this paper, we propose a novel method for lowering process temperature of SPC. This method involves the induction of high frequency alternating magnetic field during crystallization annealing, referring this process as Alternating Magnetic Field Crystallization, AMFC.

2. Experiments

The general configuration of experimental apparatus is similar to a solenoid type induction heating system, as shown in Fig. 1. The system consists of 14-turn solenoid coil for generating alternating magnetic field. The frequency of magnetic field is 14 KHz. The graphite susceptor located at the center of induction coil, similar to induction heating system is heated by induction heating. The of this system from the conventional induction heating is that the size of graphite susceptor is well smaller than the reference depth of induction heating. This set-up prevents the large portion of generated magnetic field from being consumed by graphite heating. The sample is laid on the graphite susceptor and heat treated at various temperatures. The intensity of magnetic field is changed by induction coil current [8]. In order to maintain a constant temperature at various coil currents, the sizes of graphite is adjusted accordingly. The surface temperature of heated glass is measured by induction-shielded thermocouple molded to the glass surface. The measured temperature value was found to agree well with pyrometer measurements within 5 ℃. The 500 Å-thick amorphous Si films are deposited on glass substrate (Corning 1737) using plasma enhanced chemical vapor deposition at 320 ℃. The deposited samples are annealed at various temperatures and coil currents. The progress of crystallization is

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Manuscript received February 5, 2003; accepted for publication March 21, 2003.
This work was supported by a grent under 2001 Hong-Ik University Academic Research Support Fund.
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evaluated by measuring transmittance of Si films using UV spectrometer [9].

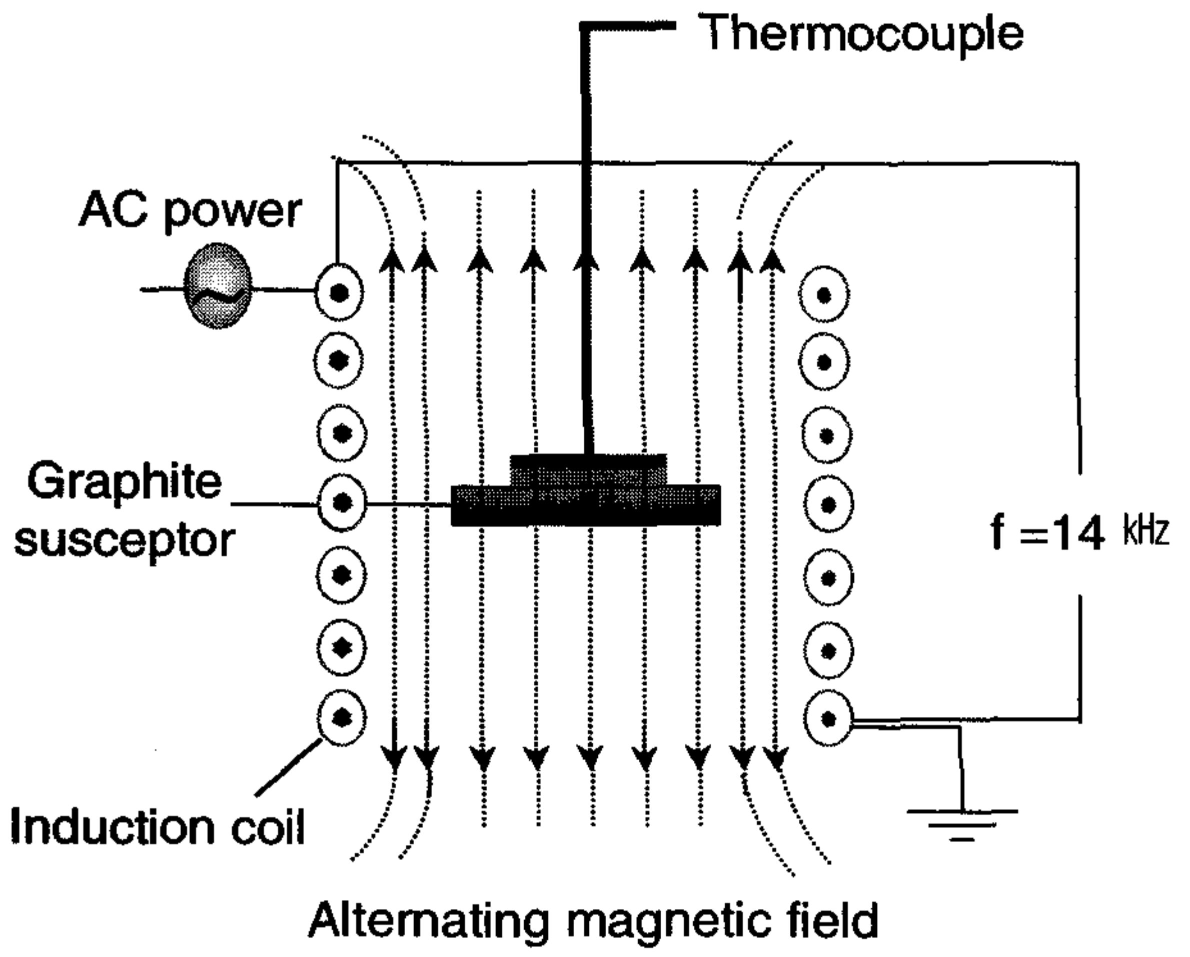
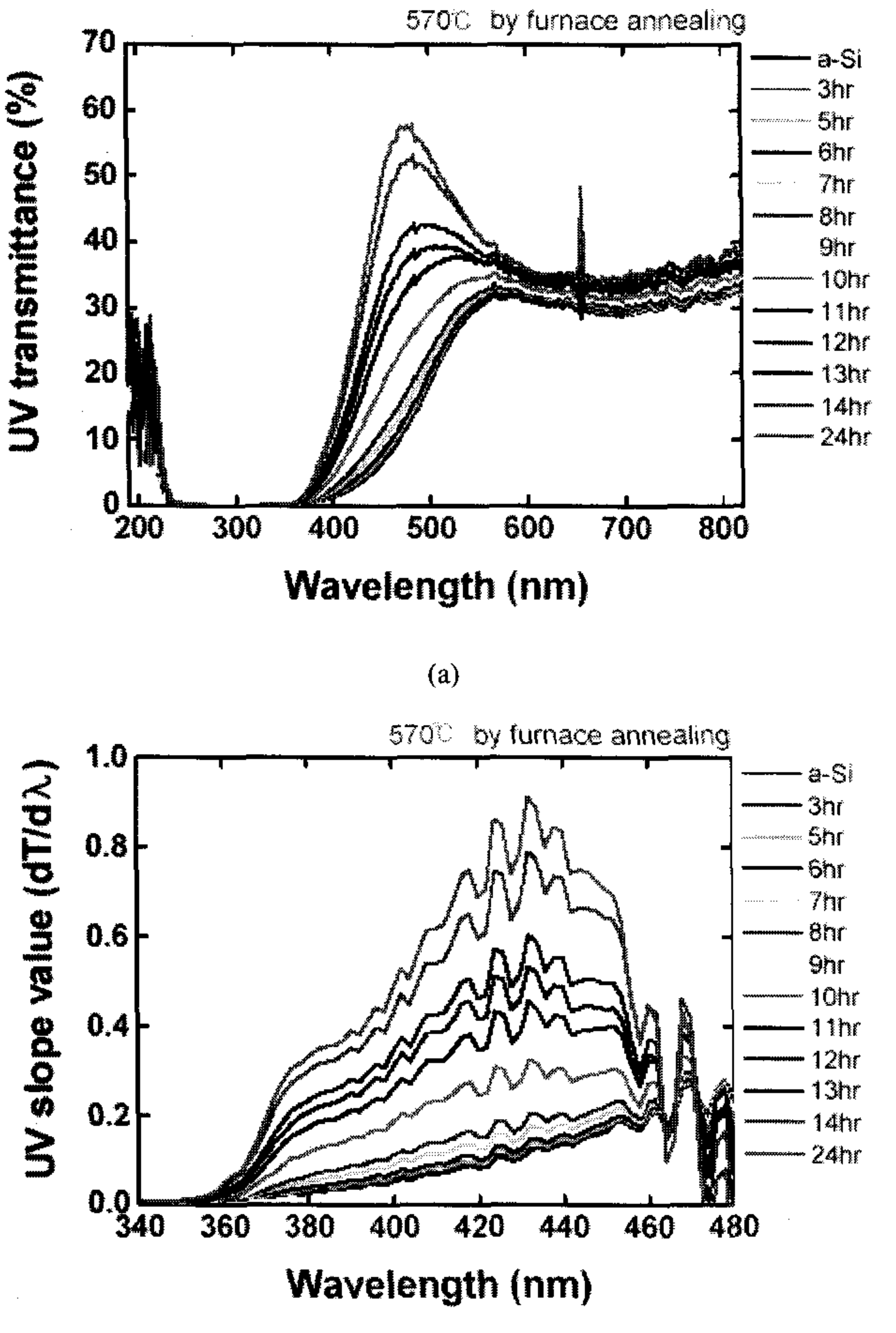


Fig. 1. Schematic diagram of alternating magnetic field crystallization system.



(a)

(b)

Fig. 2. The changes of UV transmittance with the increase in annealing time in the conventional furnace at 570 ℃.

3. Results and Discussion

We first, investigated the crystallization behavior in furnace annealing in the absence of magnetic field. It is found that the measurement of UV transmittance of Si films is a simple and useful method for characterizing the degree of crystallization in the sample after annealing. Fig. 2 shows the changes of transmittance with the increase in annealing time in the conventional furnace at 570 ℃. As the crystallization proceeds, the transmittance peaks at optical wavelength of 400~600 nm are evolved. A notable feature of those peak evolutions is the increase of peak slope around 400 nm. We plotted the slope value (i.e., $dT/d\lambda$) as a function of wavelength, λ, as shown in Fig. 3. Then, we determined the maximum slope values at 430 nm and compared those values with the results of the Raman analysis. The maximum slope value was then compared with the percentage of poly-Si in the films, as shown in Fig. 4. The linear dependency between the two values was observed, supporting the validity of UV method for evaluating crystallization degree.

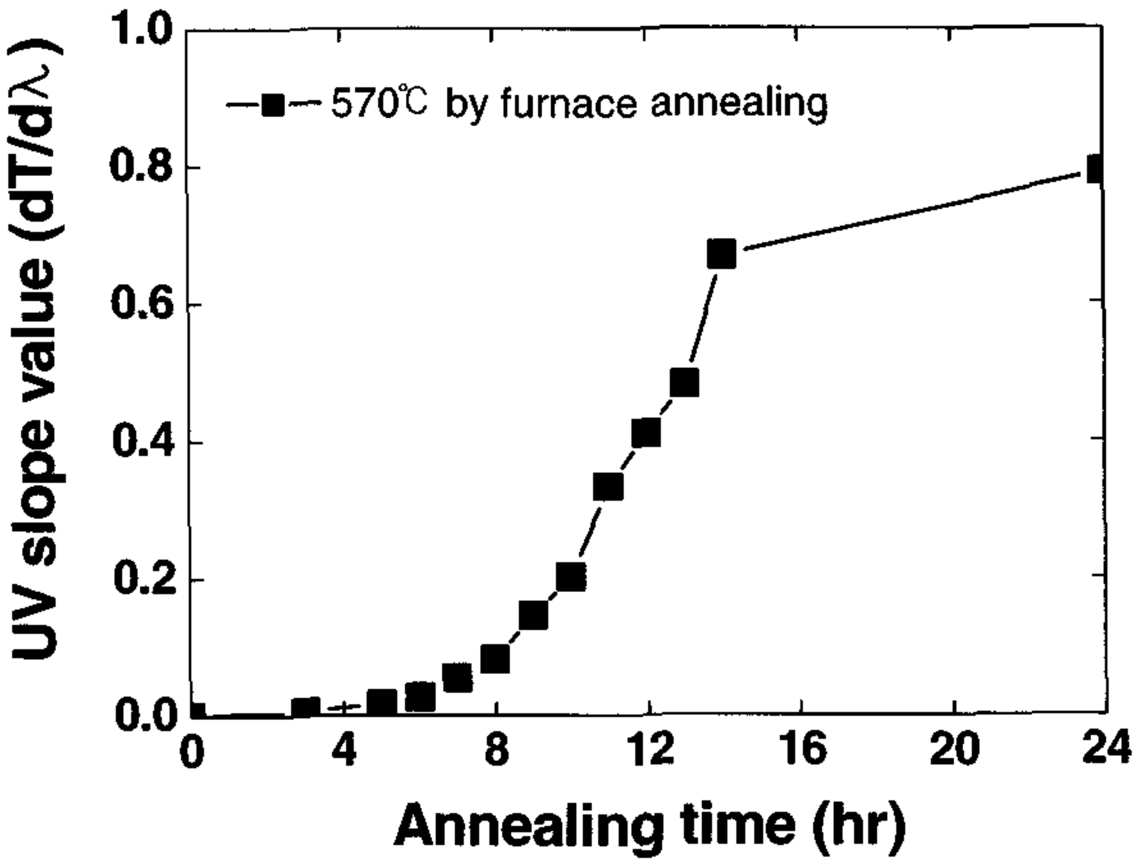


Fig. 3. The slope value as a function of wavelength.

We investigated the strength of magnetic field inside the solenoid coil in the AMFC system. Fig. 5 shows the strength of magnetic field with coil current, which was measured using a gauss meter. From the Figure the magnetic field linearly increases with coil currents, in accordance with analytical expression given by $H=4\pi nI/10L$, where H is field strength in Oe, n is coil turn number, I is coil current in led amperes and L is coil length in centimeters [10]. To study the effect of magnetic field on crystallization kinetics, we annealled amorphous Si films at 580 °C for various coil currents. For these experiments, we adjusted the size of graphite to obtain identical temperatures at various coil currents. Since the graphite size is the smaller than the reference depth dimension of induction heating, the smaller graphite size requires higher coil current to heat the sample up to the same temperature value.

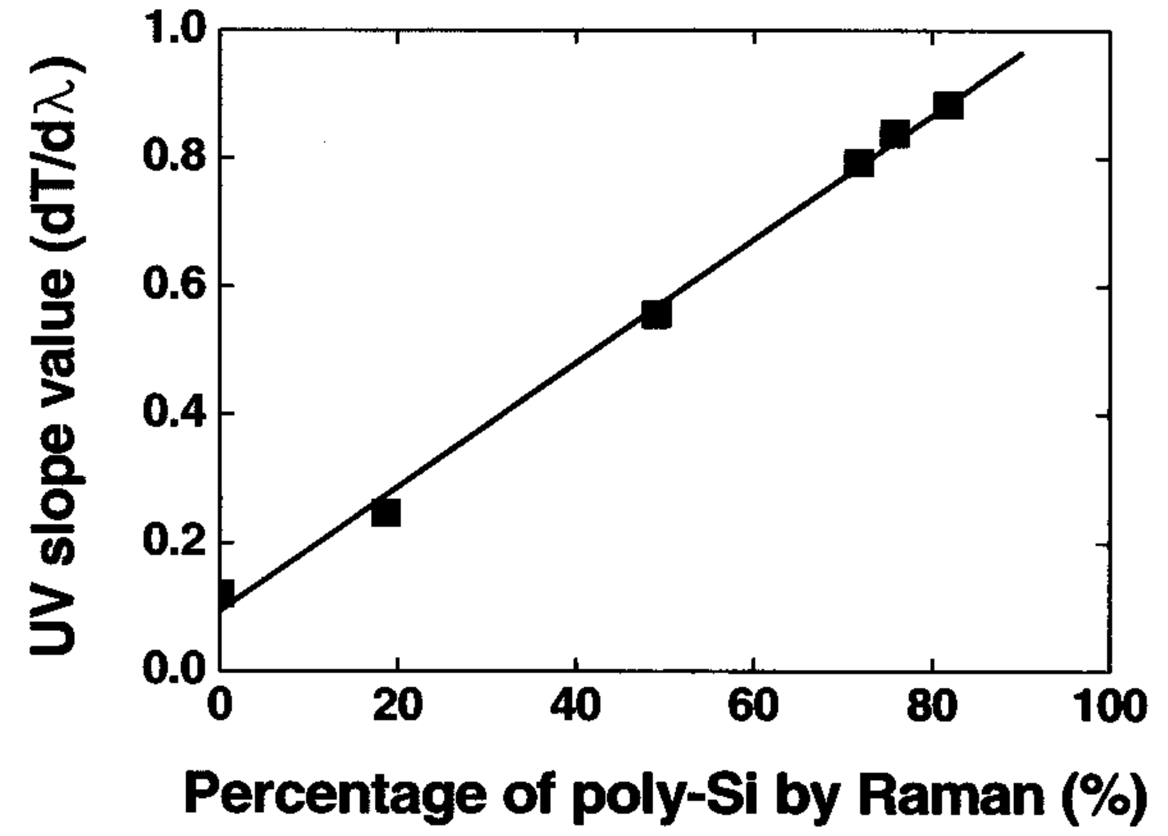


Fig. 4. Comparison of UV slope value with percentage of poly-Si in the films by Raman spectroscopy.

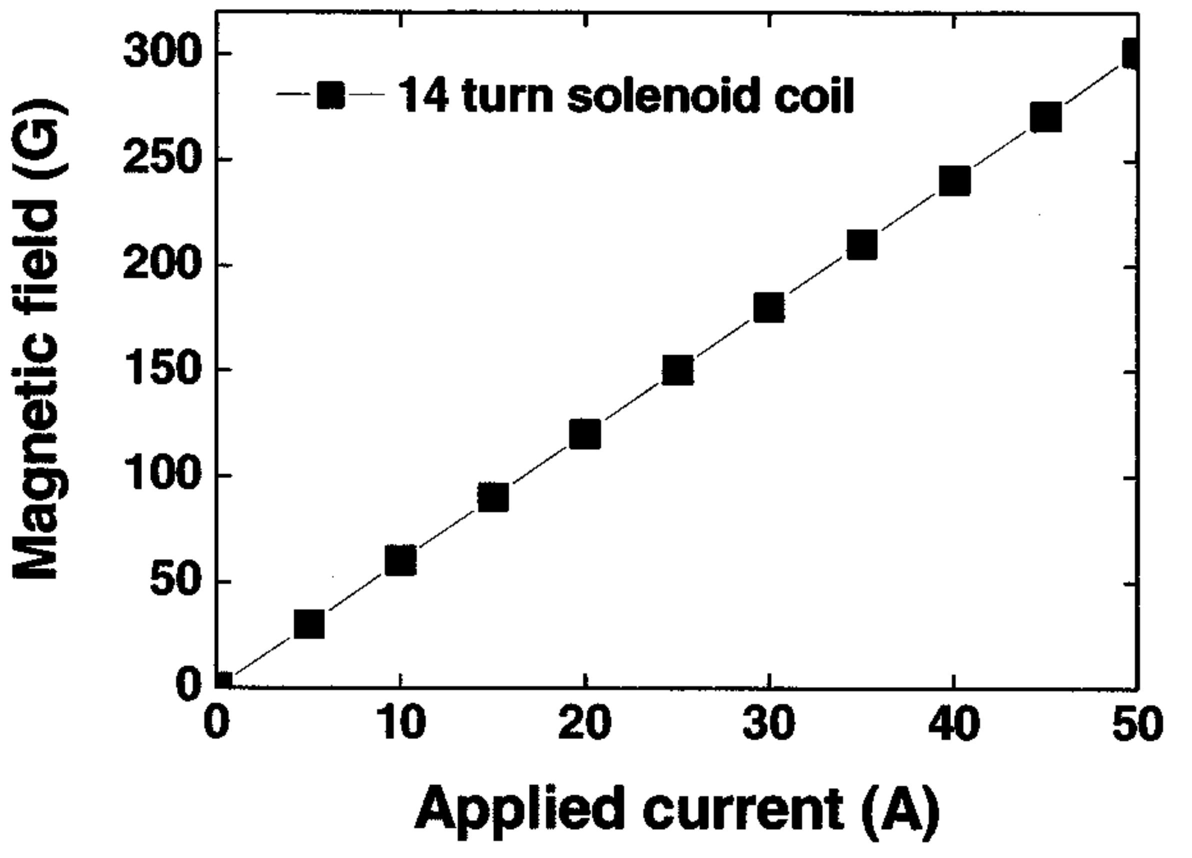


Fig. 5. The strength of magnetic field inside the solenoid coil in the AMFC system.

Fig.6 shows the crystallization for various coil currents. As shown in the figure, the crystallization rate was remarkably enhanced by increasing coil current. At the coil current of 20 amperes, crystallization was not completed even after 3 hrs of annealling. In contrast, crystallization was completed less than 20 minutes when the current was in creased to 50 A. The annealing time to achieve the half crystallization (that is, annealing time at UV slope value where of saturation value is half) is plotted against coil current in Fig. 7. The logarithm of half crystallization time versus coil current shows linear dependency. From the extrapolation of the linear dependency, the half crystallization time in the absence of magnetic field is expected to be approximately 10^3 mins. This value is close to experimental value (~12 hrs) in the case of conventional furnace annealing without magnetic field.

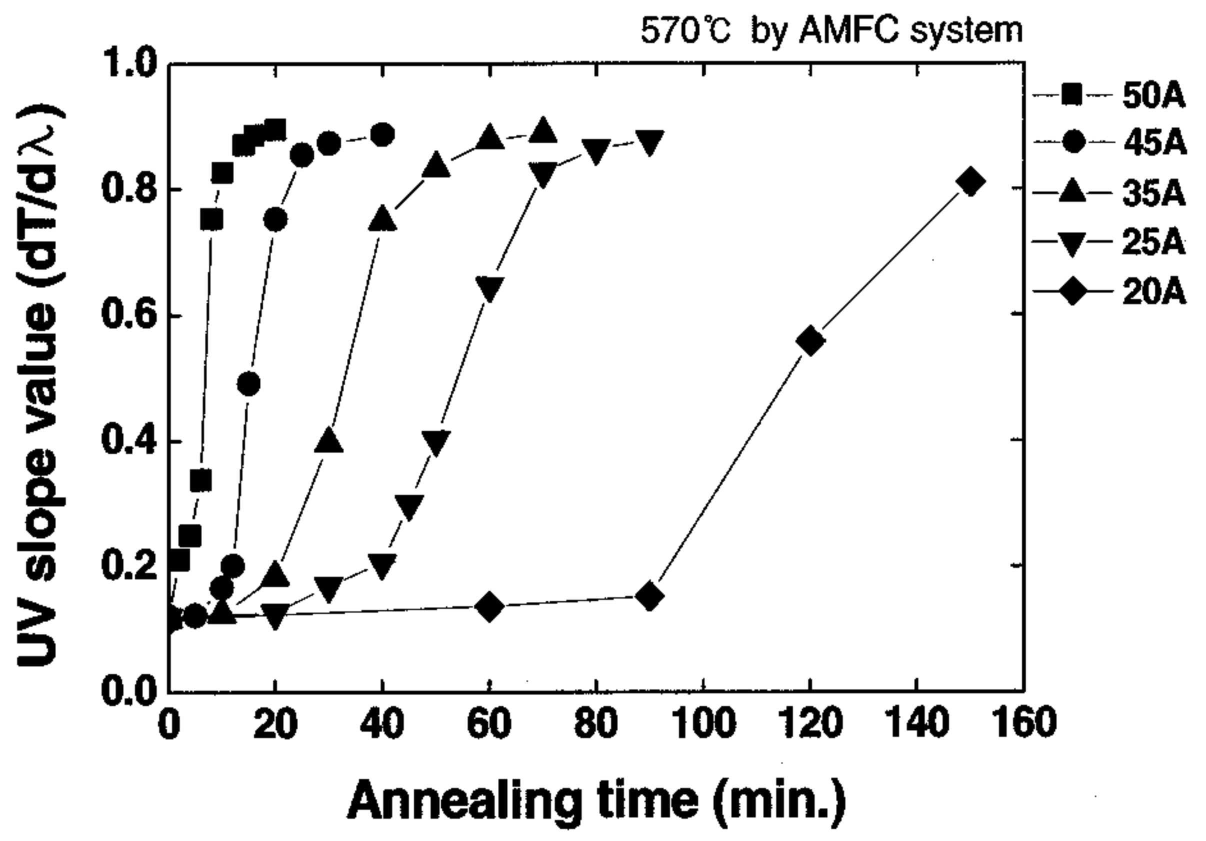


Fig. 6. The crystallization for various coil currents.

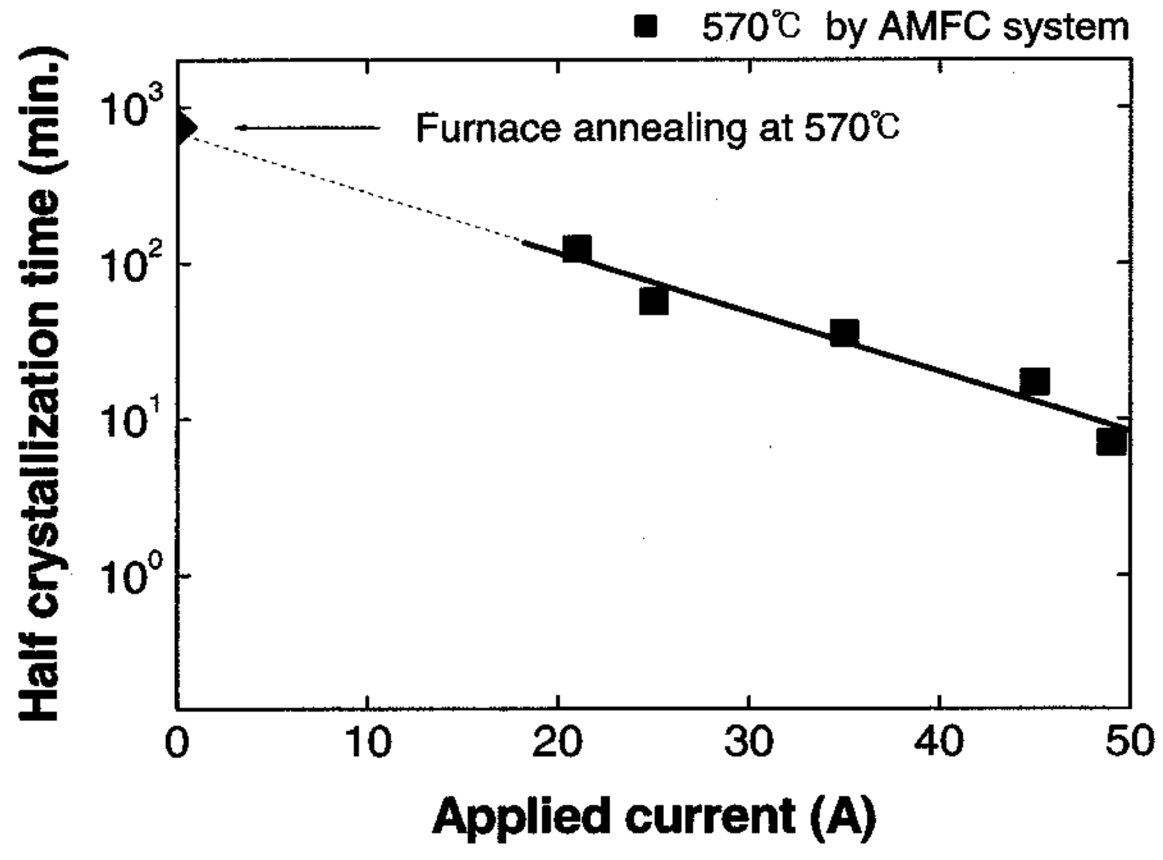


Fig. 7. Logarithm of half crystallization time against coil current.

Detail mechanism of enhanced crystallization rate by alternating magnetic field is not yet fully understood. It is well known that alternating magnetic field generates an electromotive force voltage (EMF) based on the well-known Faraday law, EMF=10^{-8} $N\left(\frac{d\Phi}{dt}\right)$, where N is the coil turns, Φ is the magnetic flux, and t is the oscillation time [11]. We believe that the enhancement of crystallization is associated with the generation of electric field during crystallization anneals. Several workers have reported that the application of electric field increases the crystallization rate [12,13]. A similar mechanism can be fourd to be applled in the AMFC of present work.

Theoretical explanation of the field-induced enhancement has yet not been reported. One possible explanation is well-known joule heating through eddy current. When amorphous Si is heated at high temperatures, the increase of electrical conductivity of Si film may lead to a joule heating effect. However, preliminary thermal analysis using experimental parameters suggests that selective joule heating of 500Å-thin Si film should not lead to a significant temperature increase. Therefore, some non-thermal effects should be considered for crystallization enhancement. Atomic arrangement in amorphous Si has a number of broken bonds and charge dipoles in the tetrahedral covalent bonding network. Those dipoles can be forced to move through applied electric field. It seems likely that field-induced oscillation of dipoles will modify the potential fields of atomic bonding network, thus, improving the kinetics of crystallization [14]. Based on this atomistic model, we are currently carrying out molecular dynamic simulations, which will be published at a later time.

4. Conclusions

We investigated the crystallization of amorphous Si films under alternating magnetic field. The application of magnetic field was found to have significant effects on the kinetics of crystallization. The increase of magnetic field was observed to enhance the crystallization rate or lower the crystallization temperature. Such enhancement was attributed to the electric field generated by the alternating magnetic field.

References

[1] A. Nakamura, F. Emoto, and E. Fujii, J. Appl. Phys. **66(9)**, 1. November (1989).

[2] K. T. Y. Kung and R. Rief, J. Appl. Phys, **59**, 2422 (1987).

[3] D. R. Hamilton and R. G. Sedensticker, J. Appl. Phys, **31**, 1165 (1960).

[4] J. A. Bhat, Z. Jin, and H. S. Kwok, IEEE. Electron. Dev. Lett, **20**, February (1999).

[5] T. K. Kim, T. H. Ihn, and B. I. Lee, Jpn. J. Appl. Phys, **37** 4244, August (1998).

[6] Man Wong, Zhonghe Jin, Gururaj A. Bhat, Philip C. Wong, and Hoi Sing Kwok, IEEE. Electron. Dev. **47**, May (2000).

[7] S. Y. Yoon, S. J. Park, K. H. Kim, J. Jang, Thin Solid Films **383**, 34 (2001).

[8] S. Ainn and S. L. Semiatin, "Elements of Induction Heating", ASM International (1998).

[9] V. Iordanov, J. Bastemeijer, R. Ishihara, P. Sarro, A. Bossche, and M.Vellekoop, 627, SeSens (2002).

[10] A. Doison, M. Park, D. Mills, "Introduction to Magnetic Maerials", 24, Addison Wesley (1972).

[11] A. Doison, M. Park, D. Mills, "Introduction to Magnetic Maerials", 35, Addison Wesley (1972).

[12] S. H. Park, S. I. Jun, K. S. Song, C. K. Kim and D. K. Choi, Jpn. J. Appl. Phys. **38**, L108 (1999).

[13] J. N. Lee, Y. W. Choi, B. J. Lee, and B. T. Ahn, J. Appl. Phys. **82** (6), 15 September (1997)

[14] O. Stasiw and J. Teltow, Ann. Der Phys., **1**, 261 (1947).