Transactions of the Materials Research Society of Japan 31[2] 507-510 (2006)

Direct deposition of microcrystalline Si films on large size glass substrate by internal ICP source

E.Takahashi, H.Kaki, M.Fujiwara, Y.Nishigami, K.Kubota, T.Hayashi, K.Ogata, A.Ebe* and Y.Setsuhara**
R&D Laboratories, Nissin Electric Co., Ltd. 47 Umezu, Takase-cho Ukyo-ku Kyoto 615-8686
Fax: 81-75-864-4878, e-mail: Takahashi_Eiji@nissin.co.jp
*EMD Corp. 12-1 Shimizu-cho Saiin Ukyo-ku Kyoto 615-0052,
**Joining and Welding Research Institute Osaka University, 11-1 Mihogaoka Ibaraki Osaka 567-0047

A novel ICP source with internal antenna has been developed to synthesize microcrystalline silicon film on glass substrate at low temperature under 300℃. We have developed the equipment which could introduce the corning 1737 glass of 600×720mm^2 in size for substrate. It was found that high density with low potential SiH_4/H_2 plasma was generated by ICP source. The plasma potential could be maintained less than 25V with increase of plasma density up to 5×10^{10}cm^{-3}. Raman and TEM analysis revealed that highly crystallized microcrystal Si films were synthesized without incubation layer. There was few degradation of crystallinity with increase of deposition rate. In order to evaluate the applicability of uc-Si films to the display devices, bottom gate type TFT was fabricated. It was found that the TFT employing an optimized uc-Si layer exhibited a field effect mobility of 3cm^2/Vs which was one order higher than typical a-Si TFT.
Key words: uc-Si, PECVD, ICP, TFT, LCD,

1. INTRODUCTION

The large area liquid crystal display for TV (LCD-TV) has been developed intensively and grew huge market in the last decade. The hydrogenated amorphous silicon (a-Si:H) thin film is widely applied to bottom gate type thin film transistor (BG-TFT) for driving the active matrix LCD. In the recent trend, the mother glass substrates for LCD-TV become more than 2m in size to reduce the production cost. There exist significant issues for uniformity over large area deposition.

Otherwise, hydrogenated microcrystalline silicon (μc-Si) thin film has superior characteristics compared with a-Si:H film, including a higher carrier mobility and reliability. Indeed, the direct deposition of good quality low temperature μc-Si film is highly desirable and constitutes a promising alternative. A lot of methods have been proposed for synthesizing the μc-Si film, such as PECVD, a method using SiF_4 gas that utilizes the etching effect of fluorine and catalytic-CVD [1-3]. However, there also exist difficulties in large area deposition and good quality for TFT.

As for the PECVD methods, it was found that hydrogen radicals play an important role in crystallization of uc-Si film [4]. High rate and high quality uc-Si deposition also requires high density and low plasma potential. The inductive coupled plasma (ICP) sources with internal antenna are promising way to produce such plasma condition over large area. Various type of ICP sources have been reported for the application of large area FPD [5-7]. However, there were few reports focusing on the direct deposition of uc-Si over large area glass substrates.

In this study, we have developed novel inductive coupled plasma (ICP) source which has internal low inductance antenna (LIA-ICP) unit. This LIA-ICP unit could produce high density and low potential plasma in terms of reduction of capacitive coupling with plasma. There is no limitation of deposition area because the plasma uniformity could be controlled by arranging the LIA-ICP unit distribution. The highly crystallized uc-Si with good interface quality could be synthesized by LIA-ICP units. The characteristics of BG-TFT with uc-Si have been measured to evaluate their applicability to display devices.

2. EXPERIMENTAL APPRATUS

Figure 1 shows a schematic diagram of uc-Si film deposition equipment. A large size plasma process chamber was fabricated to evaluate the large area plasma uniformity. The substrate size was 600 × 720mm^2. U-shaped low inductance antenna covered with insulator was designed to decrease the inductance element. LIA-ICP units were installed to the vacuum chamber at the optimized position. An rf power of 13.56MHz was fed to each antenna through a conventional matching network. The total high frequency power of 15kW was supplied to LIA-ICP unit. The process chamber was exhausted by a dry pump and a turbo molecular pump to a base pressure of less than 1×10^{-4}Pa.

Hydrogen and Silane gases were used as material gases. The gases were uniformly introduced through a gas inlet port. The working pressure during deposition was kept constant at 0.665Pa in all experiments. The substrate temperature was kept at 300℃. The plasma parameters were evaluated by Langmuir-probe method and OES. The crystallinity of uc-Si films were examined by Raman spectroscopy and TEM.

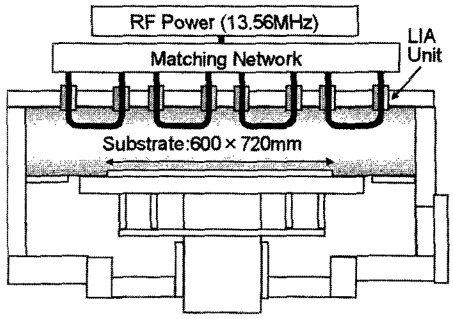

Fig. 1. Schematic diagram of LIA-ICP source.

The BG-TFT devices were fabricated and its electrical characteristics were measured in order to evaluate the applicability of uc-Si films to display devices. A 100nm-thick gate insulator (G.I) layer was formed on the low-resistant (1-10Ωcm) n-type Si-wafer, followed by the deposition of 50nm-thickness uc-Si film on the G.I film by means of LIA-ICP. An Au film of 300nm thickness was deposited on the G.I film, and the circular source electrode and the ring shaped drain electrode were fabricated by lift-off process. Typical dimensions of L and W were 500 and 628μm, respectively.

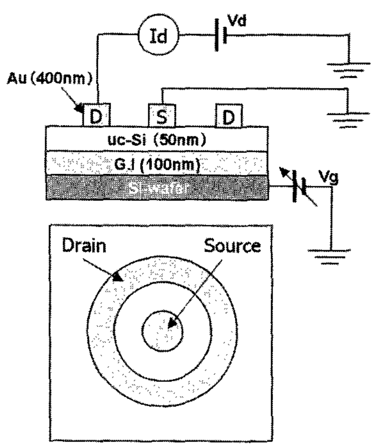

Fig. 2. Bottom gate type TFT structure.

3. RESULTS AND DISCUSSION

The plasma parameters under the same deposition process condition of uc-Si deposition were analyzed by using a Langmuir probe as shown in Fig.3. The working pressure and SiH_4 flow rates was set at 0.67Pa and 20ccm, respectively. The RF power were changed in the range of 2-15kW. The Ne increase with increase of RF power, and reached $5\times10^{10}cm^{-3}$. Comparing with our conventional VHF (60MHz) CCP process [4], The electron density Ne was one order higher of magnitude at the same RF power density. LIA-ICP could produce high density plasma comparing to VHF CCP.

The Vp and Vf were decreased with increase of RF power. LIA-ICP plasma showed low Vp and Vf value even though higher RF power was introduced. The differential between Vp and Vf represents ion energy irradiating to glass substrate during deposition. The Vp-Vf was about 10eV at the case of LIA-ICP plasma. It means that LIA-ICP plasma could decrease uc-Si / gate insulator interface damage, and could increase crystallization of uc-Si film. Furthermore, the Ne was approximately 10 times higher than VHF CCP process, which means the possibility of higher deposition rate of uc-Si film than VHF CCP.

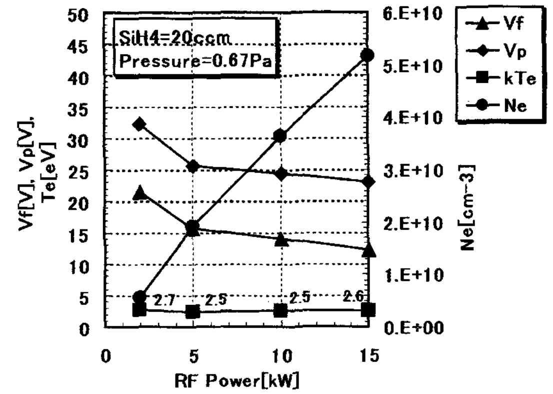

Fig. 3. Plasma diagnostics by Langmuir probe.

Figure 4 shows a relation between deposition rate and RF power as a function of SiH_4 flow rate. Deposition rate increases with increase of RF power, and achieved over 50nm/min at the case of 10kW, 100ccm. There was no saturation behavior of deposition rate with RF power. It was estimated that high deposition rate over 100nm/mn could be achieved if higher RF power and SiH_4 flow rate were introduced at the film deposition.

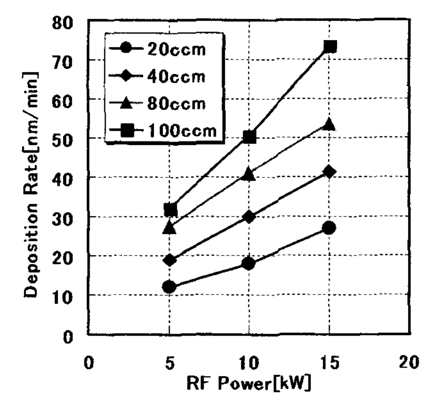

Fig. 4. Deposition rate of uc-Si films.

The film thickness uniformity was evaluated at the substrate of $600\times720mm^2$ glass. The thickness uniformity resulted in $\pm5.5\%$. The film thickness uniformity could be controlled by arranging the distribution of LIA-unit. We could deposit uc-Si film without limitation of substrate size by LIA-ICP.

The crystallinity of uc-Si films were evaluated by Raman analysis. In the Raman spectra, T.O phonon peaks at $520cm^{-1}$ were contributed to Si crystal, and broad peaks around $480cm^{-1}$ were contributed to amorphous phase. The crystallinity was calculated from $Xc=I_{520}/(I_{520}+I_{480})$. Figure 5 shows a relation between Xc and deposition rate comparing with films which were synthesized by VHF CCP method. All uc-Si films with the thickness of 50nm showed high Xc over 90%. There was few degradation of crystallinity with increase of deposition rate. Otherwise, regarding uc-Si films by VHF CCP, high crystallinity films over 90% were also obtained, however, these films showed the degradation with increase of deposition rate. Then, LIA-ICP method could obtain highly crystallized uc-Si films at high deposition rate in spite of 50nm thickness. It was estimated that the interface of uc-Si films could have high crystallinity.

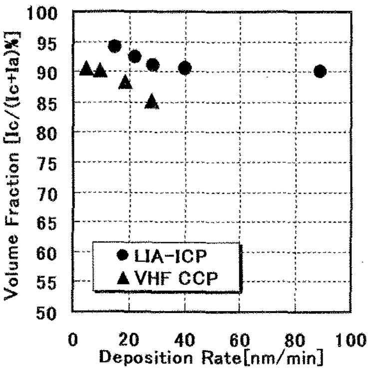

Fig. 5. Crystal volume fraction by Raman spectra.

In order to analyze film structure at the interface of G.I, the cross-sectional TEM analyses were performed as shown in Figure 6. It was found that the columnar grains with 10nm-20nm in lateral size grew from the interface. We could synthesize uc-Si films without any incubation layer at the interface by means of LIA-ICP, which means the capability of applying uc-Si films to the BG-TFT.

Fig. 6. Cross-sectional TEM image (D.R=20nm/min).

In order to investigate the capability of TFT channel layer grown by LIA-ICP, BG-TFT's as shown in Figure 2 were fabricated. The typical transfer and output characteristics were shown in Figure 7 (a) (b), respectively. The TFT electrical characteristics for mobility and threshold voltage were extracted using the drain current in the saturation regime. From the transfer characteristics with Vds = +10V, the off-current Ioff and on-current Ion are defined as the minimum and maximum current, respectively. The on-off ratio is given by Ion/Ioff and the subthreshold slope is defined as the inverse maximum slope. The extracted TFT parameters are summarized in Table I.

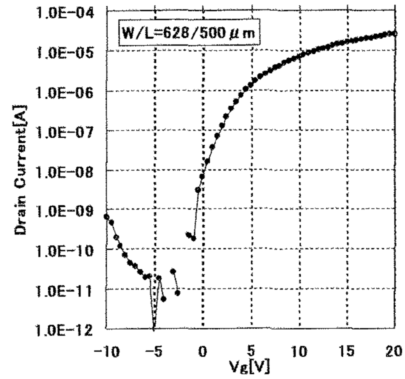

Fig. 7(a). TFT Transfer characteristic.

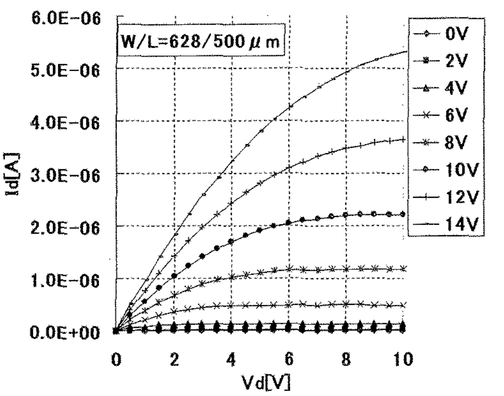

Fig. 7(b). TFT output characteristic.

Table I. TFT characteristics.

Field effect mobility μ_e	3.00 [cm^2/Vs]
Threshold voltage V_{th}	1.53 [V]
Sub-threshold Slope S	0.25 [V/dec]
Ion/Ioff ratio	5×10^6

It was found that the electron mobility was one order higher than typical a-Si:H TFT, and Ion/Ioff ratio achieved 5×10^6 which has an applicability to switching device for LCD.

The uniformity of TFT characteristics in $600\times720mm^2$ glass substrate was also evaluated. 9 TFT's were fabricated at optional points in glass substrate. It was found that there were no distinct differences among TFT characteristics. All TFT showed the leakage current of less than 1×10^{-11}A, and showed Ion/Ioff ratio over 10^6. Therefore, it was estimated that the distribution of LIA-ICP unit does not affect TFT characteristics. We could design the PECVD equipment with LIA-ICP for large glass substrate.

4. CONCLUSIONS

A novel ICP source with internal antenna unit was developed as PECVD equipment for large glass substrate. It was found that the plasma potential generated by LIA-ICP showed low value less than 25V in spite of having a high plasma density up to $5\times10^{10}cm^{-3}$. It was estimated that these phenomena were related from the antenna unit which has low inductive element. The highly crystallized uc-Si films with crystalline volume fraction of over 90% were achieved. There was few degradation of crystallinity with deposition rate up to 90nm/min. TEM analysis revealed that there was no incubation layer at the interface, because LIA-ICP could generate large amount of hydrogen radicals that were necessary for Si nucleation. The BG-TFT's were fabricated to evaluate TFT characteristics of uc-Si films. It was found that the TFT employing an optimized uc-Si layer exhibited a field effect mobility of 3cm2/Vs which was one order higher than typical a-Si TFT.

REFERENCES

[1] A.Matsuda: J. Non-Cryst. Solids 59 (1983) 767.
[2] T. Akasaka, Y. Arai, M. Nakata and I. Shimizu: Jpn. J. Appl. Phys. 32 (1993) 2607.
[3] H. Matsumura: Jpn. J. Appl Phys. 37 (1998) 3175.
[4] H. Kirimura, K. Kubota, E. Takahashi, S. Kishida, K. Ogata, Y. Uraoka and T. Fuyuki: Jpn. J. Appl. Phys. 43 (2004) 7929.
[5] Y. Wu and M. A. Lieberman: Plasma Souces Sci. Technol. 9 (2000) 210.
[6] M. Kanoh, K. Suzuki, J. Tonotani, K. Aoki, and M. Yamage: Jpn. J. Appl. Phys. 40 (2001) 5419.
[7] K. N. Kim, Y. J. Lee, S. J. Jung and G. Y. Yeom: Jpn. J. Appl. Phys. 43 (2004) 4373.

(Received December 19, 2005; Accepted March 2, 2006)