Applied Physics Letters

# Fabrication of poly-Si films by continuous local thermal chemical vapor deposition on flexible quartz glass substrate

T. Nakamura, H. Kuraseko, K. Hanazawa, H. Koaizawa, Y. Uraoka, T. Fuyuki, and A. Mimura

Citation: Applied Physics Letters **93**, 241503 (2008); doi: 10.1063/1.3013839
View online: http://dx.doi.org/10.1063/1.3013839
View Table of Contents: http://scitation.aip.org/content/aip/journal/apl/93/24?ver=pdfcov
Published by the AIP Publishing

**Articles you may be interested in**

Kinetic roughening of amorphous silicon during hot-wire chemical vapor deposition at low temperature
J. Appl. Phys. **101**, 024915 (2007); 10.1063/1.2424527

Switching behavior of microcrystalline silicon deposited by hot-wire chemical vapor deposition
J. Appl. Phys. **97**, 073709 (2005); 10.1063/1.1866486

Charge transfer between thermally deposited α-naphthyl-phenyl-diamine and chemical-vapor-deposited homoepitaxial diamond films
Appl. Phys. Lett. **83**, 4776 (2003); 10.1063/1.1630155

Anisotropic electrical conduction and reduction in dangling-bond density for polycrystalline Si films prepared by catalytic chemical vapor deposition
J. Appl. Phys. **86**, 985 (1999); 10.1063/1.370836

Field emission conduction mechanisms in chemical vapor deposited diamond and diamondlike carbon films
Appl. Phys. Lett. **72**, 2182 (1998); 10.1063/1.121315


This article is copyrighted as indicated in the article. Reuse of AIP content is subject to the terms at: http://scitation.aip.org/termsconditions. Downloaded to IP: 132.174.255.116 On: Tue, 23 Dec 2014 20:16:38

# Fabrication of poly-Si films by continuous local thermal chemical vapor deposition on flexible quartz glass substrate

T. Nakamura,[1] H. Kuraseko,[1] K. Hanazawa,[1] H. Koaizawa,[1] Y. Uraoka,[2,a)] T. Fuyuki,[2] and A. Mimura[3]
[1]*Furukawa Electric Corp., 6 Yawata-Kaigandori, Ichihara, Chiba 290-8555, Japan*
[2]*NAIST, 8916-5 Takayama-cho, Ikoma, Nara 630-0192, Japan*
[3]*AIST, Tsukuba Central 5, Tsukuba, Ibaraki 305-8565, Japan*

(Received 13 June 2008; accepted 19 September 2008; published online 18 December 2008)

The continuous deposition of polycrystalline silicon film on quartz fiber by local thermal chemical deposition was investigated. High-speed deposition owing to high temperature and locality was examined using fixed and moving substrates. We confirmed the high-speed deposition of polycrystalline silicon and achieved a maximum speed of over 1 $\mu$m/s. Furthermore, we succeeded in a continuous deposition of polycrystalline thin silicon with a thickness of 50–100 nm on a quartz fiber with low roughness and low impurity content. Thin film transistor with a mobility more than 3.7 cm$^2$/V s was achieved by using this film. © *2008 American Institute of Physics.*
[DOI: 10.1063/1.3013839]

Low temperature polycrystalline silicon thin film transistors (TFTs) are regarded as promising for use in next generation displays.[1,2] For this purpose, low temperature fabrication of silicon films on large glass substrates with a maximum temperature of 450 °C are being widely studied.[3–6] These studies are very important for the fabrication of high-performance displays. However, if high-performance TFTs can be fabricated on quartz fibers, the applicability of the TFT will be widely extended, such as to integrated circuit tags or flexible displays. In our previous studies, we reported that polycrystalline silicon TFT can be fabricated on quartz fiber and that a deposition technique for silicon film was required.[7,8]

In this study, a novel technique for depositing silicon thin film on quartz fiber, continuous local thermal chemical deposition (CoLT-CVD), was studied. Features of the fiber are as follows. Control of the surface roughness becomes simple, low production cost is realized, and flexibility is increased owing to the thickness of substrates, as shown in Fig. 1. High endurance against high temperature process improves the reliability of the device fabricated on the fibers.[9] In order to compete the productivity by the conventional process on a wide glass substrate, a high-speed deposition technique is necessary. In our experiments, silicon film was deposited by thermal CVD at more than 1000 °C by utilizing their high thermal stability, and the film was analyzed to discuss the effectiveness of CoLT CVD.

In order to establish a high-speed deposition method, deposition speed was investigated using the system shown in Fig. 2. In a thin quartz tube with a diameter of 6 mm, silicon film was deposited onto the quartz substrate set on a carbon susceptor. Dichlorosilane (DCS) and hydrogen were used as source gases, where the concentration ratio of the two gases was varied. Range of the flow rate of DCS and $H_2$ were 100–250 SCCM (SCCM denotes standard cubic centimeter per minute at STP) and 2–3.5 slm, respectively. Deposition was performed in atomic pressure.

Source gas was introduced from the left-hand side and evacuated from the right-hand side. In the center area, a carbon susceptor was placed within a reaction tube set together with an infrared gold furnace heats the susceptor area by infrared radiation. The moving axis of substrate was set at the right-hand side of the system to move them from left to right at high speed. The moving direction was the same as the gas flow. The width and thickness of the fiber used in this experiment were 1 mm and 100 $\mu$m, respectively.

The maximum deposition speed was investigated by controlling the ratio of DCS to hydrogen. With a DCS gas concentration of over 7%, a maximum speed of 1 $\mu$m/s was obtained. By increasing the flow rate of the source gas at a fixed ratio of DCS/H2, the maximum deposition speed was measured. With increasing flow rate, maximum speed further increased, and 1400 nm/s was obtained. When the maximum temperature in the reaction tube, flow rates of DCS and hydrogen were 1250 °C, 300 SCCM, and 3 slm, respectively, the maximum deposition speed and average deposition speed were 1330 nm/min and 761 nm/s, respectively. These conditions were employed for the deposition on the moving substrates.

For the moving substrates passing though the deposition area, the deposited film thickness was calculated using the length of the deposition area and the average deposition speed. Figure 3 shows the relationship between the moving

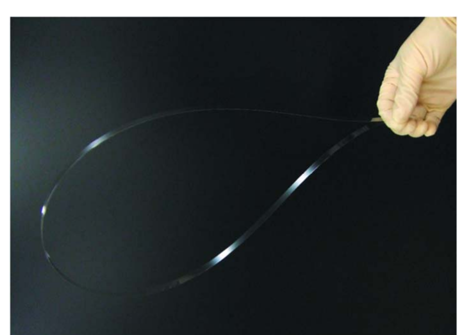

FIG. 1. (Color online) Quarts fiber used in this study.

a)Electronic mail: uraoka@ms.naist.jp.

 © 2008 American Institute of Physics

This article is copyrighted as indicated in the article. Reuse of AIP content is subject to the terms at: http://scitation.aip.org/termsconditions. Downloaded to IP: 132.174.255.116 On: Tue, 23 Dec 2014 20:16:38

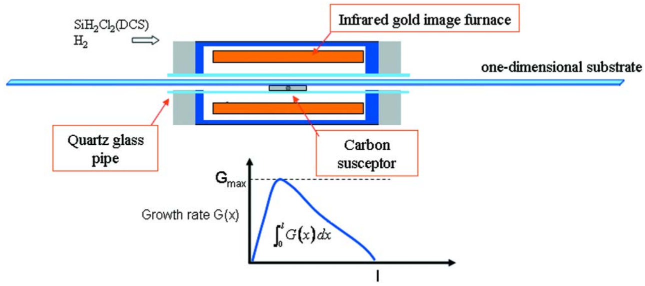


FIG. 2. (Color online) CoLT-CVD system for depositing silicon thin film on quartz fiber.

speed and film thickness obtained in the experiment and by calculation using the deposition rate. These curves suggest that the deposited film thickness can be controlled by adjusting the moving speed. Any small discrepancy will be due to the parameter obtained under the static condition. When the moving speed was high, the rates of substrate and gas flow became closer and the nominal gas flow rate decreased, therefore the deposition rate decreased.

Figure 4 shows the cross-sectional transmission electron microscopy (TEM) image of silicon thin film deposited on the moving substrate at 400 mm/s. Polycrystalline silicon film with a film thickness of approximately 50 nm was deposited on quartz fiber. The surface of the polycrystalline film was very smooth with an rms value of 2.4 nm. Raman spectrum of the silicon film was examined. Steep peak at 520 $cm^{-1}$ clearly indicated that the deposited silicon was crystallized.

The impurity profile of this film was examined by secondary ion mass spectroscopy and compared the film deposited by conventional plasma CVD. As this system is operated under atmospheric pressure, deterioration of the purity was a cause of concern. However, concentrations of oxygen and nitrogen were under $10^{20}$ atom/cc, therefore, this film was found to be comparable with that deposited under the vacuum condition.

Through these experiments, we achieved a continuous high deposition rate that could not be obtained by the conventional method. With a conventional thermal CVD system, variation of the film thickness within a wafer, from wafer to wafer and from batch to batch, is a serious problem, particularly for thin film deposition. These problems were resolved by thinning, narrowing, and elongating substrates and moving them at high speed. When the thin glass substrate moves though a high-temperature area, thermal capacitance becomes small. Furthermore, surface area increases, and consequently, markedly high heating and cooling rates were realized. Therefore, migration of silicon atom species on the substrate was suppressed and surface roughness was improved. The reaction time was as short as within 0.7 s and contamination could be minimized.

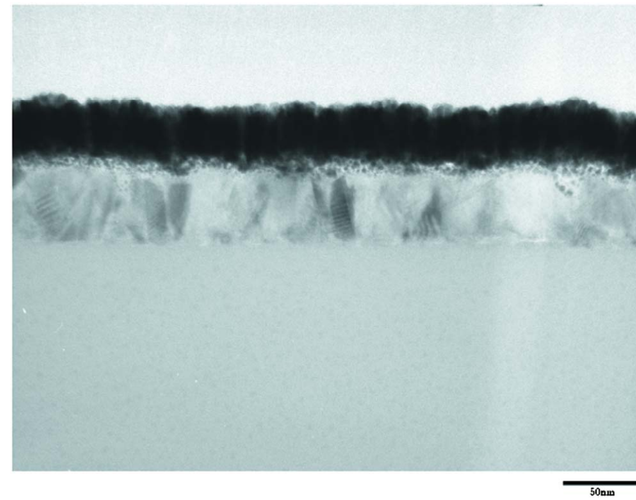


FIG. 4. (Color online) Cross-sectional TEM image of silicon thin film deposited on the moving substrate at 400 mm/s.

Finally, we fabricated TFT. It was fabricated as shown in Fig. 5. Gate oxide with a thickness of 100 nm was deposited by CVD method. Field effect mobility more than 3.7 $cm^2/V\,s$ was achieved. Electronic properties indicated that the deposited film was sufficiently crystallized and that this method is useful for the fabrication of TFT on flexible quartz glass substrate.

In conclusion, we investigated continuous silicon deposition using a band formed of thin quartz fiber and obtained polycrystalline silicon film with high crystallinity and low impurity content comparable to those obtained by

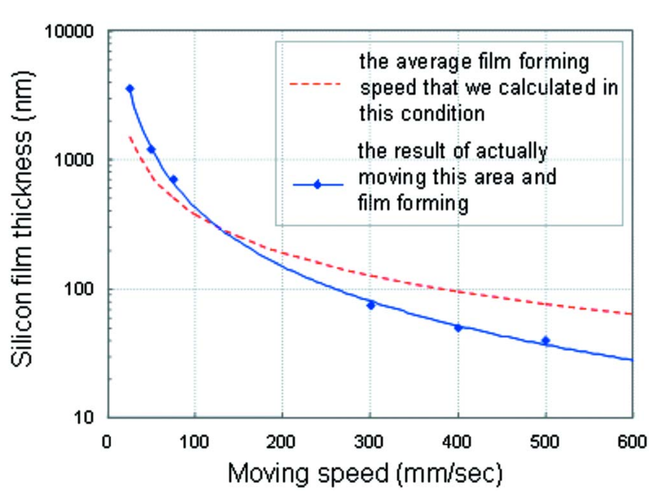


FIG. 3. (Color online) Relationship between the moving speed and film thickness obtained in the experiment and by calculation using the deposition rate.

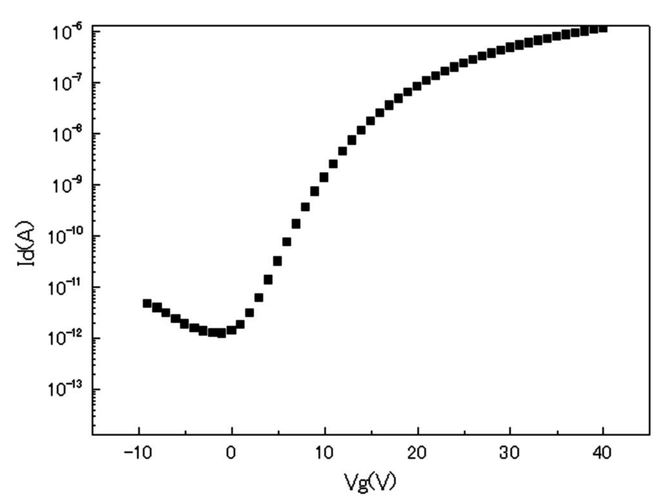


FIG. 5. Transfer curve of the thin film transistor fabricated using silicon thin film on quartz fiber. Field effect mobility more than 3.7 $cm^2/V\,s$ was achieved.

This article is copyrighted as indicated in the article. Reuse of AIP content is subject to the terms at: http://scitation.aip.org/termsconditions. Downloaded to IP: 132.174.255.116 On: Tue, 23 Dec 2014 20:16:38

the conventional vacuum process. These results demonstrated the possibility of a high-throughput process using one-dimensional substrate.

This work was performed as a part of “TFT-OLED Fabrication Techniques,” supported by the New Energy and Industrial Technology Development Organization (NEDO) project.

[1]Sharp Corporation, Press Release, August 1, 2006.
[2]Progress report of the promotion of fundamental technology research, Japan New Energy and Industrial Technology Development Organization (NEDO), March, 2005.
[3]T. Sameshima, S. Usui, and M. Sekiya, IEEE Electron Device Lett. **7**, 276 (1986).
[4]K. Sera, F. Okumura, H. Uchida, S. Itoh, S. Kaneko, and K. Hotta, IEEE Trans. Electron Devices **36**, 2868 (1989).
[5]Y. Helen, R. Dassow, M. Nerding, K. Mourgues, F. Raoult, J. R. Kohler, T. Mohammed-Brahim, R. Rogel, O. Bonnaud, J. H. Werner, and H. P. Strunk, Thin Solid Films **383**, 143 (2001).
[6]A. Pecola, F. Massusi, L. Mariucci, and G. Fortunate, Jpn. J. Appl. Phys., Part 1 **38**, 3475 (1999).
[7]Y. Sugawara, Y. Uraoka, H. Yano, T. Hatayama, T. Fuyuki, T. Nakamura, S. Toda, H. Koaizawa, A. Mimura, and K. Suzuki, Appl. Phys. Lett. **91**, 203518 (2007).
[8]A. Mimura, Y. Sugawara, Y. Uraoka. T. Nakamura, I. Shuu, T. Ikehara, T. Itoh, R. Maeda, K. Suzuki, A. Nakajima, and H. Koaizawa, in Proceedings of the AMFPD, 2008 (unpublished), p. 41.
[9]Y. Uraoka, T. Hatayama, T. Fuyuki, T. Kawamura, and Y. Tsuchihashi, Jpn. J. Appl. Phys., Part 2 **39**, L1209 (2000).

This article is copyrighted as indicated in the article. Reuse of AIP content is subject to the terms at: http://scitation.aip.org/termsconditions. Downloaded to IP: 132.174.255.116 On: Tue, 23 Dec 2014 20:16:38