Single Layer Al-Ni Interconnections for TFT-LCDs Using Direct Contacts with ITO and a-Si

Toshihiro KUGIMIYA, Yoichiro YONEDA, KOBELCO RESEARCH INSTITUTE, INC.
Hiroshi GOTOH, Nobuyuki KAWAKAMI, Electronics Research Laboratory, Technical Development Group, KOBE STEEL, LTD.

Direct contacts between aluminum alloys and thin film transistors (TFTs) contact layers were studied. An Al-Ni alloy was found to be contacted directly with an indium tin oxide (ITO) layer successfully without conventional barrier metal. The alloy was also demonstrated to be contacted directly to an amorphos-Si (a-Si) layer, if the a-Si surface is pretreated with nitridation. This development, made for the first time in TFT technology, enables direct contacts of aluminum interconnections with both ITO and a-Si. The technology has a high potential of negating the conventionally used barrier metals, making the gate, source and drain lines structures all single layered, and thus significantly improving productivity and reducing cost of TFT-LCD production. The technology has already been implemented in actual production of LCD-TFTs.

Introduction

Nowadays, Liquid Crystal Displays (LCDs) are used widely, not only for PC monitors and mobile phones, but also for large-sized TVs. KOBELCO RESEARCH INSTITUTE, INC. developed Al-Nd based sputtering targets for depositing thin-film interconnection layers with high thermal resistances and low electrical resistivities[1]. In the Al-Nd system, Nd effectively prevents "hillock", a troublesome phenomenon caused by stress-migration of aluminum, even at elevated temperatures up to 400℃, while maintaining low electrical resistivities. The addition of the rare-earth metal has only minute impact on electrical resistivities of the alloy, unlike other alloying elements which tend to increase electrical resistivities[2].

KOBELCO RESEARCH INSTITUTE, INC. also developed various other aluminum alloy sputtering target materials, exploiting the superior features of aluminum, while enabling a significant cost reduction in the manufacturing processes of LCD panels. Such alloys include aluminum alloys for direct contacts for gate, source and drain lines of Thin Film Transistors (TFTs). Each direct contact comprises a single aluminum alloy layer which requires no barrier metal, such as Mo and Cr which have been used conventionally. This article reports the direct contact characteristics of newly developed aluminum alloys, directly contacted; 1) with Indium Tin Oxide (ITO) and 2) with amorphous Silicon (a-Si).

1. Aluminum alloys for direct contacts

1.1 Advantages of aluminum alloys for direct contacts

Figure 1(a) shows the cross-section of a TFT structure, proposed by KOBELCO RESEARCH INSTITUTE, INC., which employs an aluminum alloy for direct contacts (denoted as "DC" in the figure). In conventional TFTs, stacked lines of two layers have been used for gate lines and those with three layers have been used for source and drain lines[3), 4)]. The Al alloys for direct contacts enable those interconnections to be made in single layers. The direct contacts can be made between gate lines and ITO lines at the TAB area, between source / drain lines and ITO pixel electrodes, and between source / drain lines and a-Si underlayers at the TFT area.

Figure 2 outlines the sputtering equipment used

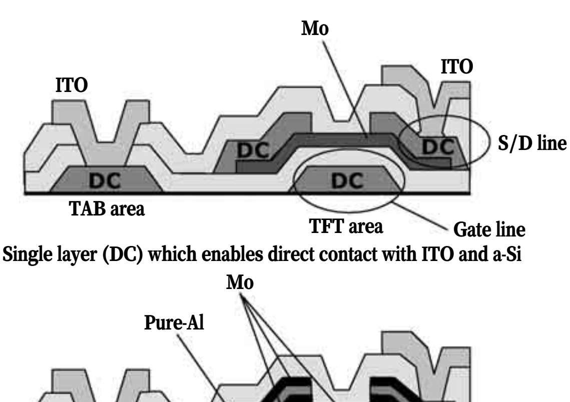


Fig. 1 Schematic configuration of cross-sectional TFT

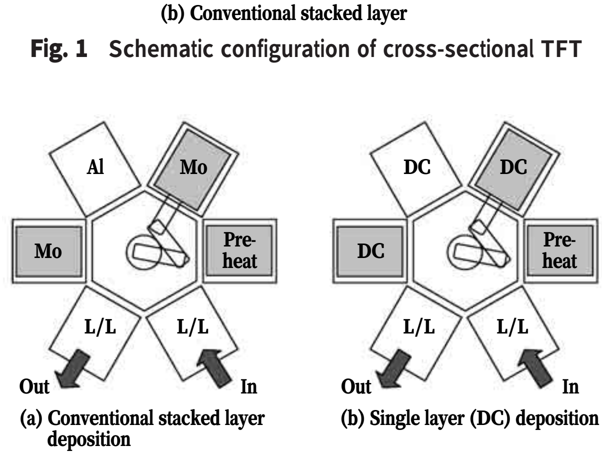


Fig. 2 Cluster-tool sputtering equipment

for deposition of aluminum alloys for direct contacts. In order to deposit thin films with conventional stacked structures, one cluster tool has to be equipped with several deposition chambers; e.g., three chambers in the case shown in Figure 2(a), in which a stacked structure with three layers is deposited. On the other hand, in the case of aluminum alloys for direct contacts, all the deposition chambers are utilized for the deposition of the aluminum alloy (Figure 2(b)) and, as a result, productivity per equipment foot print area is significantly improved. Thus the direct contact technology has significant advantages in the reduction of running cost, including reduction of barrier metals such as Mo and Cr, and in the increase of productivity, including reduction of process steps.

1.2 Technical challenges in aluminum alloys for direct contacts

1.2.1 Direct contact with ITO

Generally, ITO / Al interfaces are prone to oxidation when oxide thin films, such as ITO, are deposited directly onto Al thin films. The oxidation is thought to be caused by oxygen gas fed into the sputtering chamber during deposition of ITO film[5], oxygen radicals dissociated from water[6] and / or oxygen generated from the target material for the ITO deposition[7].

Figure 3 shows a cross sectional Transmission Electron Micrograph (TEM) of an ITO / Al-Nd interface, observed immediately after the ITO film was deposited on a surface of an Al-2at%Nd alloy film (Figure 3(a)), and the I-V characteristics of the interface (Figure 3(b)). As shown in Figure 3(a), aluminum oxide (AlO_x) is formed at the ITO / Al-Nd interface. Incidentally, an Energy Dispersive X-ray (EDX) analysis revealed the O / Al ratio, or the sub-x, to be 1.3, which is very close to the stoichiometric ratio of alumina (1.5 for Al_2O_3). Generally, I-V characteristics of MIM (Metal Insulator Metal) structures, or MIS (Metal Insulator Semiconductor) structures, exhibit conductor modes such as direct tunneling and F-N tunneling, when the thickness of the insulator layer in the middle is in the order of nano-meters. The I-V characteristics of F-N tunneling are expressed by the following formula, in which E is the electrical field applied to the insulator and J is current density.

$$J/E^2 \propto 1/E \qquad (1)$$

The I-V characteristics shown in Figure 3(b) follows the relation of the formula, indicating that F-N tunneling is occurring. In other words, in order to make the direct contacts with ITO successful, the formation of the interface oxide AlO_x should be prevented.

1.2.2 Direct contact with a-Si

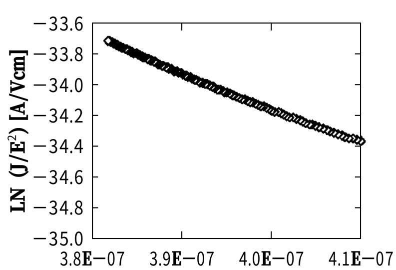
For a long time, in Large Scale ICs (LSIs), addition of Si to Al thin films and / or insertion of barrier metals, such as Ti / TiN, have been used to prevent problems associated with interdiffusion between aluminum and silicon. However, in the case of TFTs, in which Al and a-Si make contacts directly, problems associated with uniqueness of a-Si, such as dangling bonds and H-terminations, have to be solved through understanding the diffusion mode of Al in a-Si. New ideas may be required, if the mere addition of Si does not prevent the interdiffusion.

2. Experimental method and evaluation

2.1 Method for evaluating the direct contact characteristics with ITO

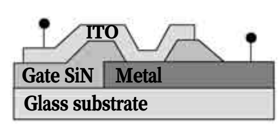
Figure 4(a) shows the cross-sectional view and (b) the structure of a Kelvin pattern used for the evaluation of the direct contact characteristics between

(a) Cross-sectional TEM image at the interface between ITO/Al-Nd

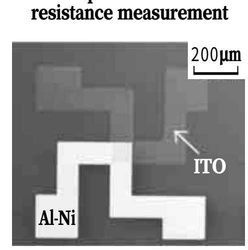


(b) I-V characteristics of ITO/Al-Nd contact

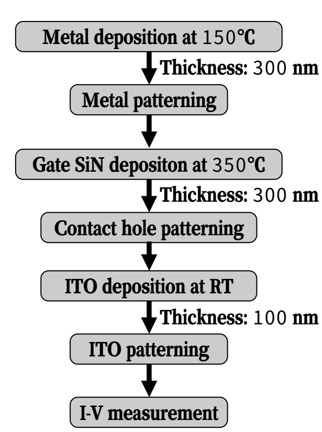
Fig. 3 ITO/Al-Nd contact analyses



(a) Cross-sectional schematic of Kelvin pattern for contact resistance measurement



(b) Top view for contact resistance measurement



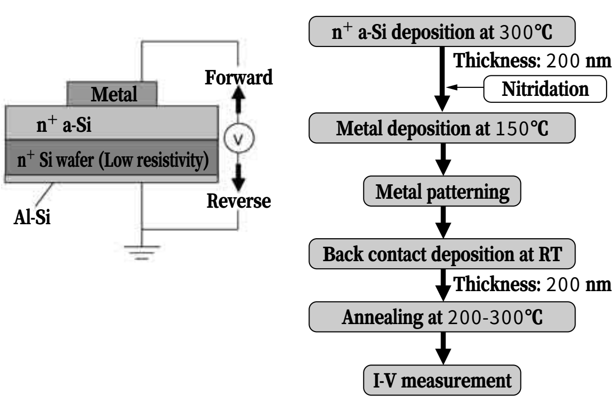
(c) Process flow for Kelvin pattern fabrication

Fig. 4 Evaluation of contact resistance measurement using Kelvin pattern device aluminum alloys and ITO. The Kelvin pattern allows measurements of contact resistances between upper and lower layers through evaluations of I-V characteristics. In this experiment, the contact area was set to be square shaped with side length of 10 μ m. In order to ensure the reliability of the results, an actual TFT manufacturing process was simulated in the fabrication of the Kelvin pattern (Figure 4(c)). The glass substrate was made of Corning 1737 and its size was 4 inches.

2.2 Method for evaluating the direct contact characteristics with a-Si

Figure 5 (a) shows the cross sectional structure of a Metal-Semiconductor (M-S) diode and (b) its preparation process. The M-S diode was used to evaluate the contact resistances between aluminum alloys and underlayer a-Si. The structure simulates both a source electrode in which electrons are injected from the metal side, and a drain electrode, in which electrons are injected from the a-Si side. In other words, contact characteristics were evaluated through I-V characteristics measured through forward and reverse current conductions as shown in Figure 5.

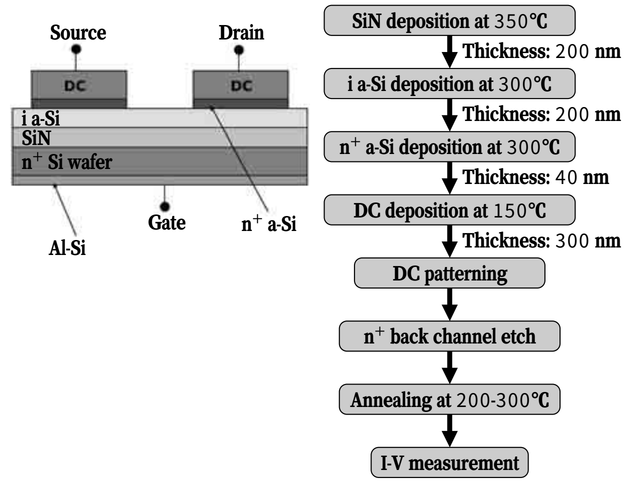
A simplified TFT was also prepared to confirm if the I-V characteristics obtained above are applicable to the I_d-V_g (drain current-gate voltage) characteristics of TFTs. The cross sectional structure and preparation process flow of the simplified TFT are shown in **Figure 6**. The structure above the a-Si surface is a typical structure used for TFTs, in which Back Channel Etching (BCE) was employed to the dry etching of the n^+ a-Si layer in the channel region. The glass substrate was made of Corning 1737 and its size was 4 inches.



(a) Cross-sectional schematic of M-S diode pattern for I-V measurement

(b) Process flow for M-S diode pattern fabrication

Fig. 5 Evaluation of I-V characteristics using M-S diode device



(a) Cross-sectional schematic of TFT for I_d-V_g measurement

(b) Process flow for TFT pattern fabrication

Fig. 6 Evaluation of I_d-V_g characteristics using TFT device

3. Experimental results and discussions

3.1 Contact characteristics with ITO

Figure 7 shows contact resistances between aluminum alloys with several different compositions and ITO. The figure also includes, as references, the results of Mo and Cr barrier metals conventionally used for the contacts with ITO. As described previously, Al-2at% Nd has a contact resistance higher than 1 MΩ, while Al-Ni alloys show sufficiently low contact resistances with ITO, with are comparable to those of conventional Mo and Cr barrier metals. The result indicates that contact resistances with ITO tend to decrease with increasing amount of Ni addition to Al.

Figure 8(a) shows the cross sectional TEM of the ITO / Al-2at % Ni-0.35at % La interface shown in Figure 7. As in the case of Al-2at%Nd, AlO_x was found to be formed at the interface between ITO and the alloy, however, an EDX analysis revealed a very small sub-x value in the range of 0.3 to 0.6. The I-V characteristics are shown in Figure 8, which shows

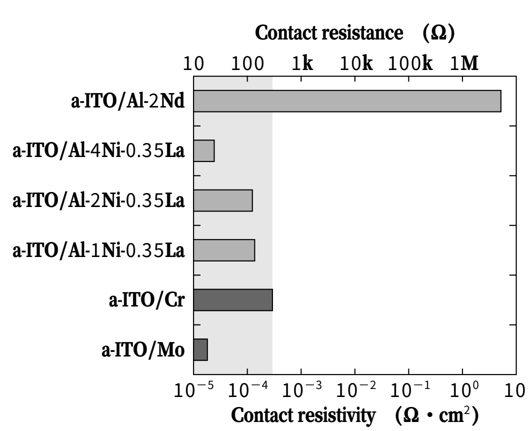
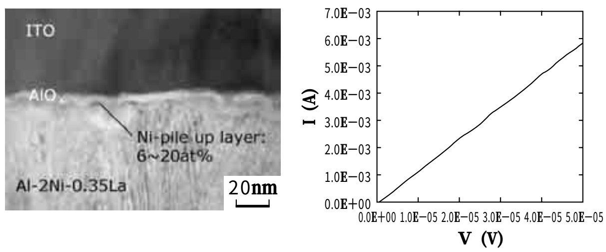


Fig. 7 Comparison of the contact resistance for various metals with ITO



(a) Cross-sectional TEM image at the interface between ITO/Al-2at%Ni-0.35at%La
(b) I-V characteristics of ITO/Al-2at%Ni-0.35at%La contact

Fig. 8 Results of ITO/Al-2at%Ni-0.35at%La interface characteristics

an ohmic relation with high linearity.

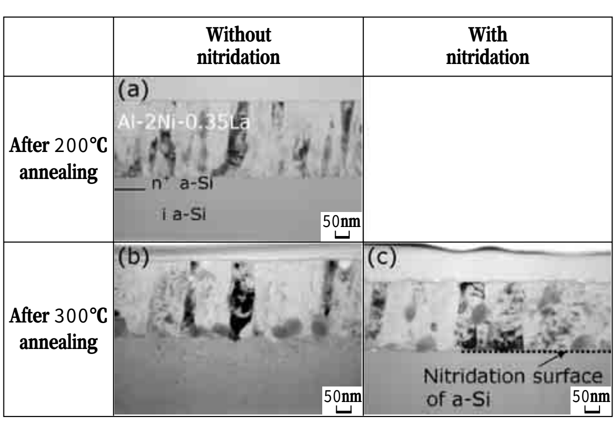
The results indicates that lower sub-x value of AlO_x increases the conductivity of the aluminum rich AlO_x and realized an ohmic characteristics. As shown in Figure 7, contact resistances with ITO depend on Ni contents. It is considered that Ni atoms, precipitate at Al grain boundaries, which means Ni atoms, which can not be dissolved into the Al matrix concentrate at the AlO_x/Al interface in a self-coherent manner, although detailed mechanisms for this behavior has not yet been elucidated.

The gate line composition was optimized at Al-2at%Ni-0.35at%La, in which the rare earth element La was added to improve the thermal resistances up to 350℃. However its addition, along with addition of Ni, was kept to a minimum to assure high conductivity after the heat treatment. Balances among other characteristics were also taken into consideration for the determination of the composition.

3.2 Contact characteristics with a-Si

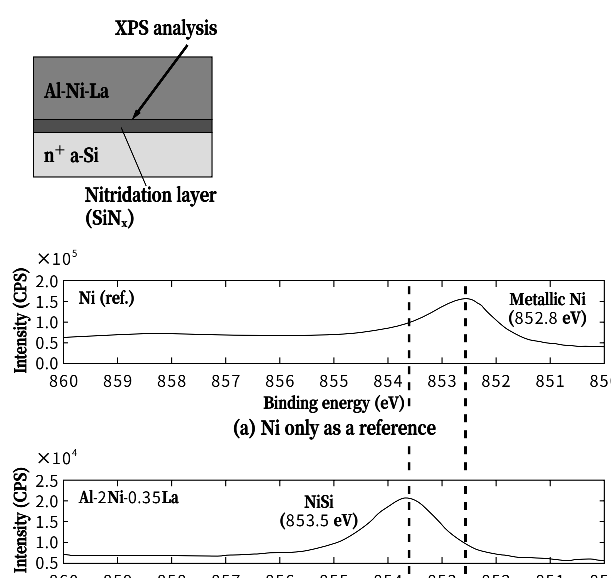
Figure 9 shows cross sectional TEMs of samples comprising Al-2at%Ni-0.35at%La sputtered on a-Si and subsequently heat treated at (a) 200℃ and (b) 300℃ in nitrogen atmosphere. No interdiffusion was observed to occur at the Al/Si interface in the sample heat treated at 200℃. In the case of the sample heat treated at 300℃, however, interdiffusion was observed. **Figure 10** shows the result of an X-ray Photoelectron Spectroscopy (XPS) analysis of the Al-Ni-La/a-Si interface heat treated at 200℃, in which no interdiffusion was observed. As clearly shown in Figure 10, a reaction layer of NiSi is formed at the interface. The reaction layer is considered to have been formed between the Ni diffused from the Al-Ni-La and the Si from the a-Si and to have prevented the interdiffusion at the Al/Si interface.

In an attempt to improve the prevention of the interdiffusion up to 300℃, at which temperature TFTs are heat treated in the final process step, a process step was added to the a-Si surface nitridation . The nitridation process includes exposure of the a-Si surface to 100% N_2 plasma for 10 second just after deposition of the a-Si layer. Figure 9 (c) shows cross sectional TEM images of samples prepared by the above nitridation process and heat treated up to 300℃. The interdiffusion has been prevented even during the heat treatment at 300℃. It is considered that the barrier effects of the NiSi reaction layer and SiNx nitridation layer are combined to increase the effect of preventing the interdiffusion. **Figure 11** shows the I-V characteristics of an M-S diode with both the above described layers, indicating that the barrier layers do not adversely affect the electric characteristics. The characteristics were compared between (a) the diode with a conventional Mo barrier metal and (b) the one with an Al-2at%Ni-0.35at%La barrier, showing that both the I-V characteristics are



(a) Al-2at%Ni-0.35at%La after 200°C annealing
(b) Al-2at%Ni-0.35at%La after 300°C annealing
(c) Al-2at%Ni-0.35at%La after 300°C annealing with nitridation of a-Si

Fig. 9 Cross-sectional TEM images



(a) Ni only as a reference
(b) NiSi formation at Al-2at%Ni-0.35at%La/a-Si interface

Fig.10 XPS analyses at Al-2at%Ni-0.35at%La/a-Si interface comparable.

Finally, the I_d-V_g characteristics of a TFT, having Al-2 at%Ni-0.35 at%La for source and drain lines and nitridation treated n^+ a-Si surface, was evaluated and the results are shown in **Figure 12**. The TFT was heat treated at 300℃ for 30 min under N_2 atmosphere after the fabrication of the source/drain lines. No degradation in I_d-V_g characteristics was observed even after the heat treatment at 300℃. **Table 1** summarizes the I_d-V_g characteristics in comparison with TFTs using Mo barrier metals for source/drain lines. As shown in Table 1, none of the samples shows any degradation of the I_d-V_g characteristics.

KOBELCO RESEARCH INSTITUTE, INC. started sample shipment of the Al-Ni-La target material in the latter half of fiscal 2005 and has already established manufacturing and shipping of the target material up to the eighth generation size. The A-Ni-La target material enabled, for the first time ever, the gate and source/drain lines of TFTs to be made as a single layer.

Conclusions

The Al-Nd target material, developed by KOBELCO RESEARCH INSTITUTE, INC., has been used as the global standard material for its thermal resistance (Hillock resistance) up to 400℃. The Al-Ni-La target material, developed this time, has almost equivalent thermal resistance as Al-Nd, while having new features enabling; 1) direct contact with ITO and 2) direct contact with a-Si in combination with nitridation of the a-Si surface; and satisfies characteristics required for direct contacts in TFTs.

We also have made possible the direct contacts between the reflection electrodes (Al-Ni-La) and pixel ITO electrodes used for mobile phone panels, which subject was not referred to in this article due to limitation of space. Gate lines, directly in contact with ITO, have already been implemented into volume production at LCD manufacturers, and so are LCD panels having reflection electrodes. Panel manufacturers are evaluating the source/drain lines proposed by KOBELCO RESEARCH INSTITUTE, INC. We will pursue volume production of aluminum alloys for direct contacts, keep developing new sputtering targets which meet the requirements of the new generations and strive to contribute to the development of the LCD industry.

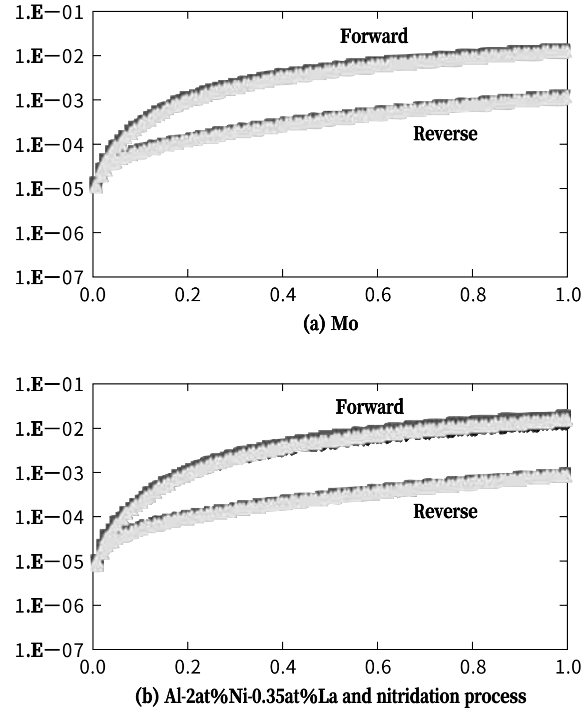


Fig.11 Forward and reverse I-V characteristics of M-S diode

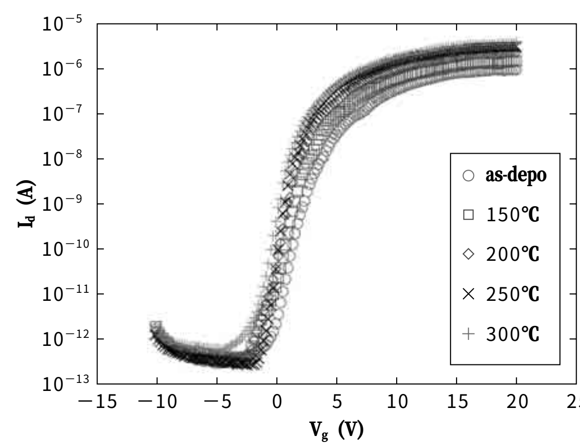


Fig.12 TFT Id-Vg characteristics after 150-300℃ annealing using Al-2at%Ni-0.35at%La and nitridation process

Table 1 TFT characteristics using various metals of S/D lines

	Mo	Al-Ni-La with nitridation
I_{on}	100%	100%
I_{off}	~pA	~pA
V_{th}	1.8 V	2.0 V
G_m	100%	100%

References

1) T. Onishi et al., *J. Vac. Sci. Technol. A*, Vol.15, p.2339 (1997).
2) J. Deutz et al., *J. Phys. F: Metal Phys.*, Vol.11, p.1787 (1981).
3) H. Takatsuji et al., *Surface and Coating Technol.*, Vol.125, p.167 (2000).
4) S. Choi et al., *SID Symp. Dig.*, Vol.36, p.332 (2005).
5) J. C. C. Fan et al., *Appl. Phys. Lett.*, Vol.31, p.773(1977).
6) S. Ishibashi et al., *J. Vac. Sci. Technol. A*, Vol.8, p.1399 (1990).
7) M. A. Nicolet et al., *Thin Solid Films*, Vol.52, p.415 (1978).
8) G. Majni et al., *Appl. Phys. Lett.*, Vol.31, p.125 (1977).
9) G. Ottaviani, *Thin Solid Films*, Vol.140, p.3 (1986).
10) F. Yonezawa et al., *"Fandamental Physics of AmorphousSilicon, Part B" edited by F. Yonezawa*, Springer-Verlag, p.119 (1981).