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Grain Boundary Structure and Bandtail Transport in High Mobility Poly-Si TFTs

Tadashi Serikawa, Seiiti Shirai, Sadao Takaoka,* Kazuo Nakagawa,*
Kenichi Oto,* Kazuo Murase,* and Shuichi Ishida**

NTT Interdisciplinary Research Labs., Musashino, Tokyo 180
* Faculty of Science, Osaka University, Toyonaka, Osaka 560
** Science University of Tokyo in Yamaguchi, Onoda, Yamaguchi 756

Two distinct regimes of weak and strong localization of electrical transport have been identified below and above the carrier trap state density $N_{st} \sim 1.0 \times 10^{12}$ cm^{-2} in the grain boundaries for high-mobility poly-Si TFTs. In both regimes, negative magnetoresistances have been observed and interpreted by the quantum interference effect. All of these features are attributed to the events in the bandtail states exponentially decaying from the bandedge, based on the observations of irregular grain boundary structure in the poly-Si film from the TEM images and the large roughness at the SiO_2/poly-Si interface from the AFM images.

1. Introduction

Poly-Si TFTs are very important for thin film semiconductor devices, especially in application to LCDs.[1] Many techniques of fabricating high quality poly-Si TFTs have been developed. However, poly-Si TFTs differ from crystalline Si MOSFETs in that grain boundaries (GBs) in poly-Si films degrade the electrical characteristics of poly-Si TFTs. A clear understanding of the GB structure with carrier trap states and the electrical transport mechanism appears to be crucial importance for any device application. In previous papers, we reported that the electrical conduction is dominated by the disorder-induced electron localization at GBs even in so-called high mobility poly-Si TFTs.[2,3,4] In this contribution, we further examine the electrical transport in such devices in more detail based on the grain boundary and interfacial structures, and we emphasize that the bandtail states play a very important role in electrical properties of high-mobility poly-Si TFTs.

2. Experimental

We fabricated N-channel poly-Si TFTs from laser-irradiated sputtered a-Si films and gate SiO_2 films sputter-deposited in an oxygen-argon mixture.[2] The densities of the carrier trap states at GBs and poly-Si/SiO_2 interfaces were reduced by furnace annealing in hydrogen-gas atmosphere. Poly-Si TFTs with mobilities ranging from 100 to 380 $cm^2/V{\cdot}s$ were fabricated by controlling laser-irradiation power. Three poly-Si TFTs with field effect mobilities and carrier trap state densities of 260 $cm^2/V{\cdot}s$ and 6×10^{11} cm^{-2} (TFT A), 200 $cm^2/V{\cdot}s$ and 1.3×10^{12} cm^{-2} (TFT C), and , 150 $cm^2/V{\cdot}s$ and 1.8×10^{12} cm^{-2} (TFT B) were measured at various conditions.

3. Results and Discussion

Figure 1 shows a plan-view TEM photograph of a poly-Si film. Neither the grain size nor the shape is uniform and the GBs are fuzzy. Potential fluctuations due to such a spatial distribution of GBs should produce the bandtail states exponentially decaying from the bandedge.[5,6] Figure 2 (a) and (b) shows atomic force microscope (AFM) photographs of the surface of poly-Si films and the 100-nm-thick gate SiO_2 films deposited on the poly-Si films. Both films have a roughness of several nanometers which are almost equal to the inversion layer thickness at poly-Si/SiO_2 interfaces. The presences of such large roughness of poly-Si film and gate SiO_2 film are also responsible to the exponentially decaying bandtail states.[7] Transport properties of our devices are experimentally demonstrated to be consistent with the bandtail conduction via extended or localized states, as follows.

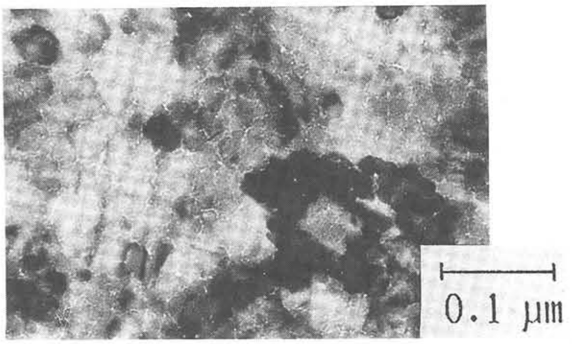

Fig. 1: TEM photograph of a poly-Si film.

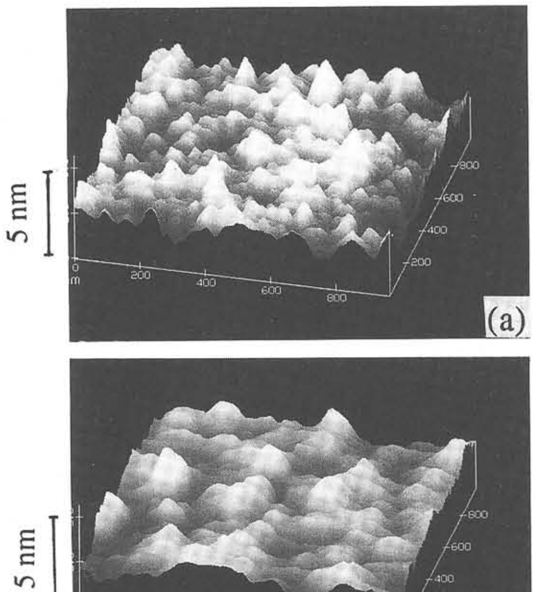

Fig. 2: AFM photographs of the surfaces of 900 nmx900 nm area for a poly-Si film (a) and a gate SiO_2 film (b).

Figure 3 shows the dependence of sheet resistance R on temperature T in the range of from 2 K to 20 K for three samples A, C and B of poly-Si TFTs at the gate voltage. The temperature dependence is plotted in the expression of w= -dln(R)/dln(T), which explicitly characterize weak- and strong- localization regimes.[8] The sheet resistance of three poly-Si TFTs of A, C, and B is, respectively, smaller than, nearly equal to, and larger than the characteristics resistance $R_0 = \pi\hbar/e^2$ (~ 13kΩ) for the crossover of metal[weak localization (WL)] -insulator [strong localization (SL)] transition in two dimension (2D).[9] As shown in Fig. 3, the slope of the temperature dependence of w changes from positive to negative as R increases. For sample A in the WL regime, w decreases with decreasing temperature because of logarithmic temperature dependence of R. For sample B in the SL regime, w increases as temperature is lowered, because of the Mott variable-range hopping (VRH) or the Efros-Shklovskii (ES) VRH as $R=R_0\exp((T_0/T)^x)$ (x=1/3 for the former and 1/2 for the latter).

In the WL regime, the Fermi level E_F is considered to lie in the extended states in the bandtail. Sample A shows a pseudometallic property in the temperature dependence of R, and the (Hall) mobility first increases with decreasing

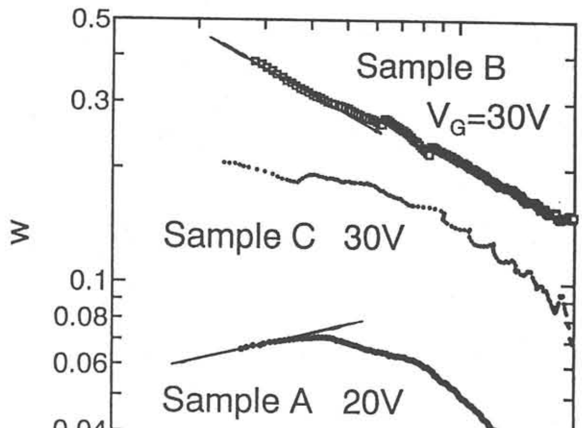

Fig. 3: Changes in w (=-dln(R)/dln(T)) as a function of temperature.

temperature from room temperature. At gate voltage 30 V, it reaches 440 $cm^2/V{\cdot}s$ near 20K. The increase of mobility indicates that phonon scattering dominates the electrical conduction in the wide temperature range. The R and the negative magnetoresistance (MR) at low temperatures are totally explained by the microscopic theory of WL.[9)]

In the SL regime where E_F is regarded to lie in the localized tail states, the transport is dominated by thermally activated conduction at high temperatures (100K -200K) and by the VRH at low temperatures where the negative MR is also observed. Below 40K, R for sample B obeys the 2D Mott VRH with x=1/3. This dependence changes to ES VRH with x=1/2 below 20K which is demonstrated in Fig. 3, in the presence of a Coulomb gap in the density of states. Figure 4 shows typical MR data in the perpendicular field on sample B at various temperatures. It was shown that the quantum interference between many hopping paths connecting the different sites leads to negative MR which grows linearly with the magnetic field B.[10)] The features in Fig. 4 are qualitatively explained by the above theory.

In both regimes of WL and SL, the Hall carrier density remains essentially constant even if the conductance is by thermally activated, which is a striking feature in the bandtail conduction of our poly-Si TFTs (phenomenally corresponding to percolating conduction).[11)] It is contrast to the Schottky barrier conduction which has been

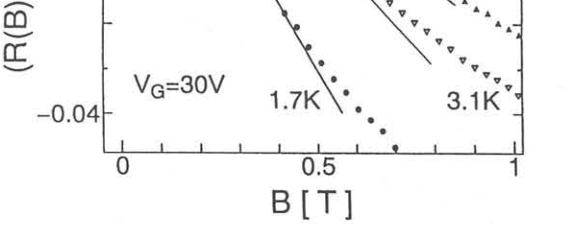

Fig. 4: Magnetoresistance of sample B at various tempereatures

seemingly applied to poly-Si TFTs with low-mobility (roughly < 50 $cm^2/V{\cdot}s$) where both carrier density and conductance increase with increasing temperature.

4. Conclusions

We have proposed a novel transport mechanism with random potential fluctuations for high mobility poly-Si TFTs instead of Schottky barrier conduction model. Moreover, it was experimentally demonstrated that the bandtail states due to the grain boundary structure and the surface morphologies of poly-Si and gate SiO_2 films play essential roles in the transport properties.

Acknowledgments

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