

CdTe/CdHgTe 코어셸 나노입자를 이용한 P채널 전계효과박막트랜지스터의 전기적특성

김동원, 조경아, 김현석, 김상식
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Electrical characteristics of Field Effect Thin Film Transistors with p-channels of CdTe/CdHgTe Core-Shell Nanocrystals

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Abstract Electrical characteristics of field-effect thin film transistors (TFTs) with p-channels of CdTe/CdHgTe core-shell nanocrystals are investigated in this paper. For the fabrication of bottom- and top-gate TFTs, CdTe/CdHgTe nanocrystals synthesized by colloidal method are first dispersed on oxidized p⁺ Si substrates by spin-coating, the dispersed nanoparticles are sintered at 150°C to form the channels for the TFTs, and Al₂O₃ layers are deposited on the channels. A representative bottom-gate field-effect TFT with a bottom-gate SiO₂ layer exhibits a mobility of 0.21cm²/Vs and an Ion/Ioff ratio of 1.5×10² and a representative top-gate field-effect TFT with a top-gate Al₂O₃ layer provides a field-effect mobility of 0.026cm²/Vs and an Ion/Ioff ratio of 2.5×10². Al₂O₃ was deposited for passivation of CdTe/CdHgTe core-shell nanocrystal layer, resulting in enhanced hole mobility, Ion/Ioff ratio by 0.25, 3×10³, respectively. The CdTe/CdHgTe nanocrystal-based TFTs with bottom- and top gate geometries are compared in this paper.

1. Introduction

Recently, field effect TFTs based on inorganic nanoparticles have been researched because of their higher mobility and better physical and chemical stabilities than organic TFTs. Especially, TFTs based on solution-processable inorganic materials have been attracted attention since they are applicable to flexible devices [1-3]. For the development of inorganic nanoparticle based TFT devices, it is necessary to improve the carrier mobility and on/off current ratio as well as the stability of the devices. Core/shell nanoparticles are more stable in chemical properties than single material-based nanoparticles because of surface passivation by the shell materials. A variety of Core-shell structured nanocrystals have been developed because of surface passivation and more robust than basic organic capped single material-based nanocrystals. For the enhancement of light-emission, the type-I core-shell nanocrystal[4-5] which core material have lower bandgap than that of shell material have been developed. Nevertheless, the type-I core-shell nanocrystals are not appreciate structures because of the confinement of charge carriers in the core; the structure does not allow the charge carriers to transport in the channel. For the nanocrystal-based TFT, the type-II core-shell nanocrystal[6] in which core material have higher band-gap than that of shell material have been attracted for transportation of the charge carriers in the channel; the type-I core-shell nanocrystals are sintered to form the channel consisting of necked HgTe shells between the source and drain. This motivates the preparation of CdTe/HgTe core-shell nanocrystals and the fabrication of these nanocrystal-based TFTs. In this study, solid films are formed on a Si substrate with the CdTe/CdHgTe nanocrystals synthesized by colloidal method[7], the CdTe/CdHgTe nanocrystals based TFTs are fabricated, and their electrical properties are characterized. In this study, CdTe/CdHgTe nanoparticles based TFTs were investigated by the comparison with the electrical properties of three types TFTs which are the bottom-gate TFT, the bottom-gate TFT with surface passivated by Al₂O₃, and the top-gate TFT.

2. General instruction

2.1 Experimental Method

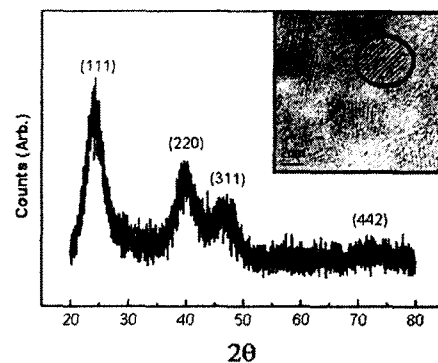
The synthesis of CdTe/CdHgTe nanocrystals is as follows. A 10 ml of CdTe nanocrystals dispersed water was diluted to 100 ml, and 0.19 g of Hg(ClO₄)₂·6H₂O and 42 μl of 1-thioglycerol were added subsequently to this solution of which pH was adjusted to 11.6 with 1M NaOH. The

solution was then purged with nitrogen for 30min. And then under stirring, H₂Te gas which was generated by the reaction of 0.084 g of Al₂Te₃ and 10 ml of 0.5 M H₂SO₄ under N₂ atmosphere was passed through the solution together with a N₂ flow for 20 min. The CdTe/CdHgTe core-shell nanoparticles powders were obtained by the centrifuge process after the addition of isopropyl alcohol. The CdTe/CdHgTe nanocrystals were washed with methanol and acetone to remove the organic capping material of 1-thioglycerol.

A bottom gated TFT sample was fabricated by spin-coating of CdTe / CdHgTe core-shell nanocrystals on a 300 nm thick SiO₂ layer deposited on top of the p-type silicon substrate. In order to improve adhesion of the interface between the SiO₂ and the spin-coated CdTe/CdHgTe core-shell nanoparticles layer, the sample was annealed at 150 °C for 10 min. After patterning by photolithography, gold used as metal electrodes was thermally deposited. In order to surface passivation of the bottom gated TFT and fabrication of top gated TFT, 60 nm-thick Al₂O₃ was deposited by atomic layer deposit (ALD) method. And the electrodes were formed by thermal evaporation of Au (100 nm) on the top of Al₂O₃ layer. The channel length and width of the active layer (CdTe/CdHgTe core-shell nanoparticle) are 5 μm and 1 mm, respectively. The width of the gate electrode is about 3.5 μm. The CdTe/CdHgTe core-shell nanoparticles were characterized by X-ray diffraction (XRD, Philips X'Pert diffractometer), high resolution transmission electron microscope (HRTEM, JEOL, JEM-3000F) and UV-visible absorption spectra were taken with a PGENRAL TU-1800. Photoluminescence spectrum was measured using 633-nm wavelength light from a He-Ne laser as the excitation sources. An Agilent 4155C semiconductor parameter analyzer was used to measure I-V curves. All the measurements were performed under the air at room temperature.

2.2 Results and discussion

Figure 1 is X-ray diffraction (XRD) pattern of the CdTe/CdHgTe core-shell nanoparticles. The XRD peaks are matched well with those of the CdTe and HgTe microcrystallites. The broadening of the XRD peaks observed in the XRD pattern originates from the nanometer-scaled diminution of the crystallite sizes. The XRD peaks of the CdTe and HgTe nanocrystals may not be resolved; both the lattice structures of the CdTe and HgTe nanoparticles are zinc-brende, and their lattice constants



<Fig.1> XRD pattern and HRTEM image of CdTe/CdHgTe nanoparticle

are very close to each other (the lattice constants of CdTe and HgTe are 6.48 and 6.46 Å, respectively). HRTEM image taken for the CdTe/CdHgTe core-shell nanocrystals is shown in inset of Fig.1. The

HRTEM reveals that the CdTe/CdHgTe core-shell nanoparticles are single-crystalline and their average size is about 5 nm in diameter. The average size of CdTe nanoparticle without shell is about 2.5 nm. So the CdTe/CdHgTe core-shell nanocrystals shells are about 1.3 nm in thickness.

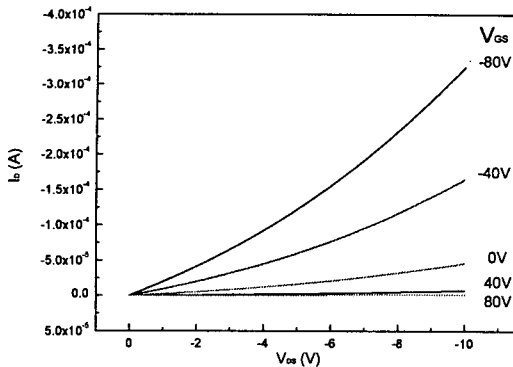


Fig.2 I_D - V_{DS} characteristics of bottom gated transistors

Figure 2 shows drain current versus drain-source voltage curves taken for bottom gate TFTs after sintering process at 150°C for 180 min. The source-drain voltage was applied from 0 to -10V. The current versus drain-source voltage characteristics reveal typical p-channel transistor. The drain-current of the CdTe/CdHgTe core-shell nanoparticle based TFT was enhanced by sintering process. The sintering process caused decreasing a distance between nanoparticles and enlargement of nanoparticle size, finally resulting in the necked CdTe/CdHgTe core-shell nanoparticles, shells act as p-channels.

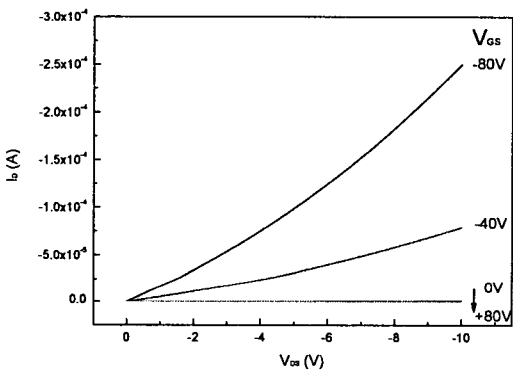


Fig.3 The I_D - V_{DS} characteristics of bottom gated TFT with passivation Al_2O_3 layer

Figure 3 shows the passivation effect of Al_2O_3 layer. The CdTe/CdHgTe core-shell nanocrystals film before passivation shows that off-current is 2.12 μA at gate voltage of +80 V. After depositing Al_2O_3 passivation layer, off-current is dramatically reduced. we got a 38 nA of off-current when V_g of +80V was applied and on-off current ratio was 3×10^3 . A remarkably decreased off-current may be caused by the effect of passivation, which prevent the adsorption of H_2O molecules and oxidation on the surface of the nanocrystal film. The characteristics of drain current versus drain-source voltage for device with a 60-nm thick Al_2O_3 as top gate dielectric materials shown in Fig. 4. The dielectric constant of Al_2O_3 is higher than SiO_2 of bottom gate dielectric materials. Therefore, operating gate voltage of top gate transistors is less than that of bottom gate transistors and controlled up to $V_g = -15V$. An on-off current ratio is 2.5×10^2 for gate voltage from -15 to 15V at $V_{DS} = -10V$. The field-effect mobilities of holes are 0.21, 0.25, and 0.026 $cm^2/V \cdot s$, for bottom gate, bottom gate after passivation process, and top gate, respectively, from the value of maximum transconductance and $\mu = g_m(L/W)/(C_g V_{DS})$ in the linear region, where L and W are the channel length and width, C_g is the capacitance per unit area of the gate oxide.

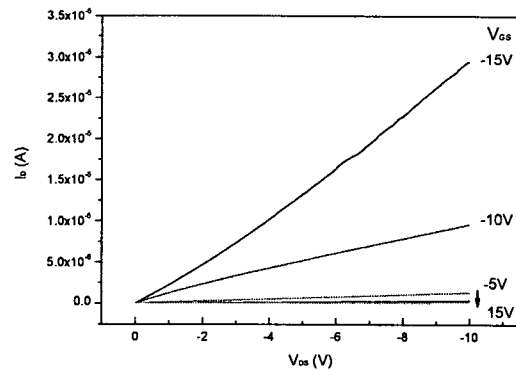


Fig.4 The I_D - V_{DS} characteristics of top gated TFT

3. Conclusion

CdTe/CdHgTe nanocrystals were synthesized by colloidal method. We have fabricated the p-channel TFTs by spin-coating of CdTe/CdHgTe core-shell nanocrystals and photolithography process. And then the CdTe/CdHgTe nanocrystal-based TFTs were compared with a top gate, a bottom gate. We observed that sintering process enhanced electrical properties and a leakage current was reduced by Al_2O_3 passivation process as results of a hole mobility, I_{on}/I_{off} ratio enhanced by 0.25 cm^2/Vs , 3×10^3 . The top-gate field-effect TFT with Al_2O_3 layer provides a field-effect mobility of 0.026 cm^2/Vs and an I_{on}/I_{off} ratio of 2.5×10^2 .

[References]

- [1] Ridley, B.A., Nivi, B. & Jacobson, J. M. "All-inorganic field effect transistors fabricated by printing", *Science*, 286, 764-749, (1999)
- [2] Baoquan Sun, Henning Sirringhaus "Solution-Processed Zinc Oxide Field effect Transistors Based on Self-Assembly of Colloidal Nanorods", *Nano letters*, 5, 2408-2413 (2005)
- [3] Talapin, D. V. & Murray, C.B. "PbSe nanocrystal solids for n - and p-channel thin film field-effect transistors", *Science*, 310, 86-89 (2005)
- [4] Klimov, V. I.; Mikhailovsky, A. A.; Xu, S.; Malko, A.; Hollingsworth, J. A.; Leatherdale, C. A.; Eisler, H.-J.; Bawendi, M. G. "Optical Gain and Stimulated Emission in Nanocrystal Quantum Dots", *Science*, 290, 314. (2000)
- [5] Peng, X.; Schlamp, M. C.; Kadavanich, A. V.; Alivisatos, A. P. "Epitaxial Growth of Highly Luminescent CdSe/CdS Core/Shell Nanocrystals with Photostability and Electronic Accessibility" *J. Am. Chem. Soc.*, 119, 7019 (1997).
- [6] Sungjee Kom, Vrent Fisher, Hans-Jurgen Eisler, and Mounji Bawendi "Type-II Quantum Dots: CdTe/CdSe(Core/Shell) and CdSe/ZnTe(Core/Shell) Heterostructures" *J. Am. Chem. Soc.*, 125, 11466-11467 (2003).
- [7] M.T. Harrison, S.V. Kershaw, M.G. Burt, A.Eychmuller, H.Weller, A.L. Roach, "Wet chemical synthesis and spectroscopic study of CdHgTe nanocrystals with strong near-infrared luminescence" *Material Science and Engineering* B69-70, 355-360 (2000)