Characteristics of Pentacene Thin Film Transistors with Stacked Organic Dielectrics for Gate Insulator

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Abstract

In this work, the electrical characteristics of organic thin film transistors with the stacked organic gate insulators have been studied. PVP(Polyvinylphenol) and polystyrene were used as gate insulating materials. Both the high dielectric constant of PVP and better insulating capability of polystyrene were compensatorily adopted in two different stacking orders of PVP-polystyrene and polystyrene-PVP. The output characteristics of the device with the stacked gate insulator showed substantial improvement compared with those of the devices with either PVP or polystyrene gate insulator. Furthermore, these stacked organic gate insulators can differently affect the TFT characteristics with the stacking orders. The electrical properties of TFTs with organic gate insulators stacked in different orders are discussed.

1. Introduction

Recently, organic(small molecule) TFTs have attracted much attention for a number of applications such as large-area sensor, smart cards, flat panel displays, and low-cost application-specific integrated circuits[1-3]. Organic semiconductors prepared using traditional methods only exhibited good performance at high gate voltages and a high dielectric constant will reduce the voltage needed to turn the device on. In this work, the electrical characteristics of organic TFTs with the different organic gate insulators and structures have been investigated. Pentacene was used as a semiconductor layer of TFTs, which is known to provide the highest field effect mobility thus far. PVP, polystyrene and stacked polystyrene-PVP, PVP-polystyrene were used as gate insulator layers, respectively. The output and transfer characteristics of the devices were measured and compared with each other. Also, for the better device performance, proper choice of solvent for PVP and dielectric layer formation process for polystyrene are taken.

2. Experimental Details

Chromium and gold were used for the gate and source/drain electrodes, respectively. The electrodes were formed by evaporations through shadow masks at room temperature. Single layers of PVP and polystyrene, and stacked layers of polystyrene-PVP and PVP-polystyrene layers were formed by spin casting on the patterned gate electrodes. Table 1 shows the speed of spin coating, the mass ratio of insulating material(wt%) and solvents of each gate insulators.

Table 1. The properties of spin-coating

	Speed(rpm)	Wt%	Solvent
PVP	3000	5	Methanol
Polystyrene	2000	1	Chloroform

Commercially available pentacene was used as a source material for the deposition. The deposition of the pentacene film on the organic insulators was carried out by heating the cell, into which the source powder was loaded, in vacuum at a pressure of about 10^{-7} Torr and at a deposition rate of 0.5 Å/sec. The

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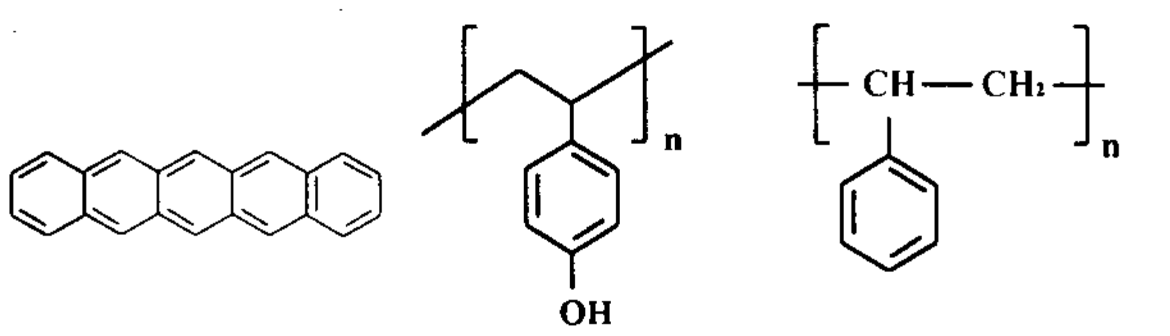
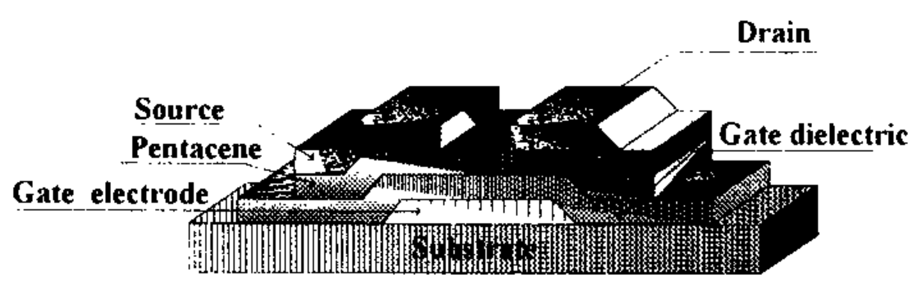
thicknesses of pentacene, PVP, polystyrene and PVP-polystyrene layers are 60nm, 300nm, 250nm and 550nm, respectively. The channel length and width of the fabricated TFTs were 150μm and 5mm. Figure 1 shows the molecular structure of the pentacene, PVP and polystyrene, and the sturucture of the device is shown in figure 2. The electrical characteristics were measured by Keithley 238 and 617 source-measurement unit.

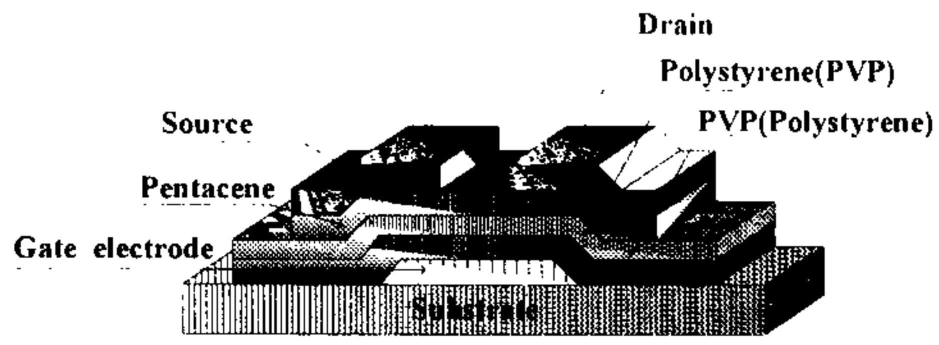


(a) pentacene (b) PVP (c) polystyrene

Figure 1. Molecular structure of (a)pentacene, (b)PVP(polyvinylphenol) and (c)polystyrene



(a) The device with single-layer gate insulator

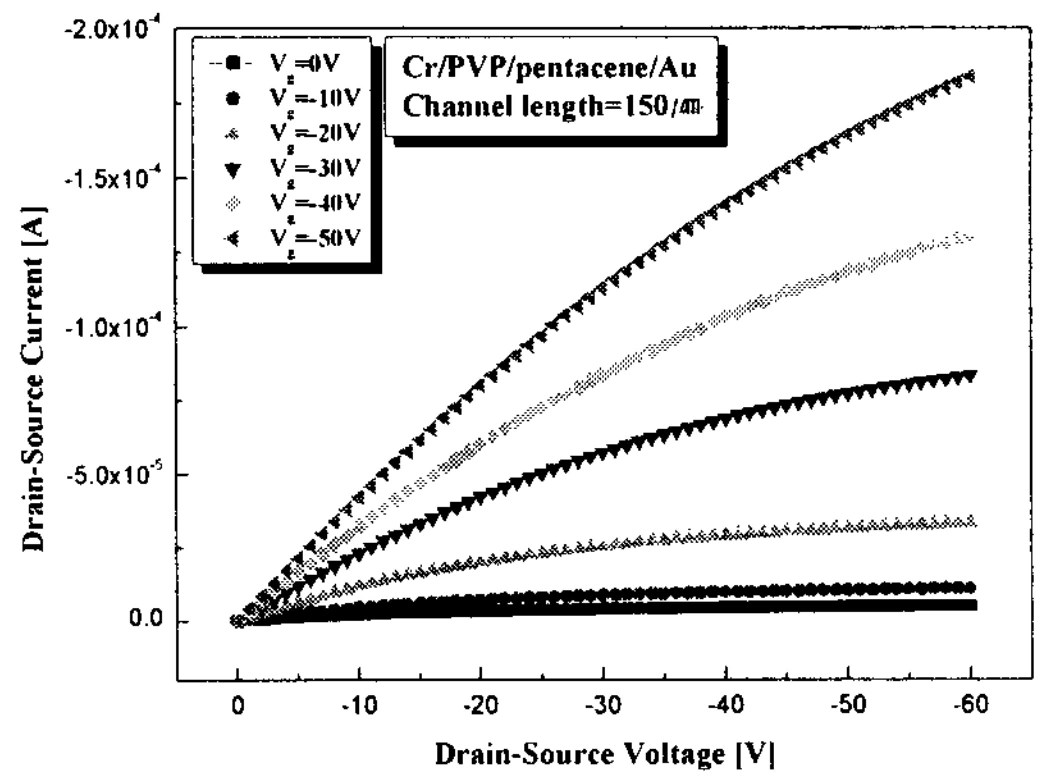


(b) The device with stacked gate insulator

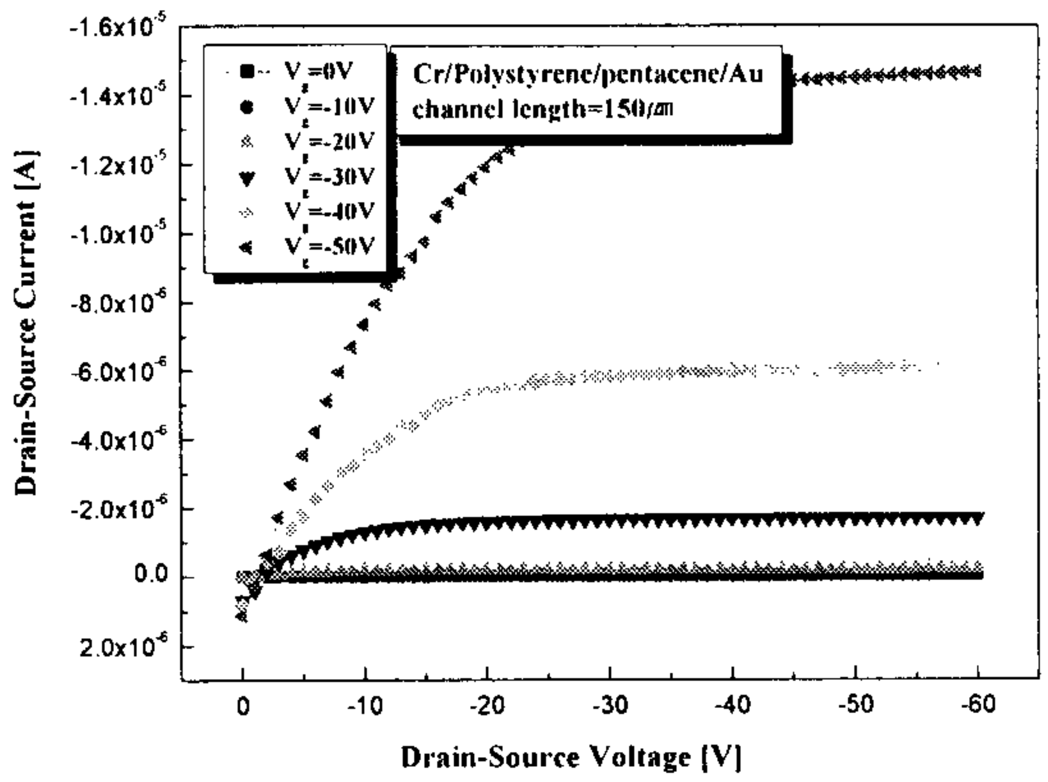
Figure 2. The structure of TFT devices with (a)single-layer gate insulator and (b)stacked gate insulators

3. Results and Discussions

The output characteristics of the pentacene TFTs with single-layer and stacked gate insulators are shown in figure 3. The device with PVP single-layer gate insulator has higher drain current level but worse current saturation aspect than the device with polystyrene single-layer gate insulator, which is attributed to the higher dielectric constant and lower insulating capability of PVP film than those of polystyrene. In figure 3(c) and (d), the drain current of the device with the stacked gate insulator is presented, which shows the improved current level compared with that of the device with the single polystyrene gate dielectric layer and the more evident saturation voltage than that of the device with the single PVP gate dielectric layer can be ascertained. These results indicate that the high dielectric constant of PVP and high insulating property of polystyrene are combined to provide these enhanced operational behaviors. Figure 4 shows the transfer characteristics of these devices. The on/off current ratios are improved by one or two orders of magnitude. The mobilities of pentacene TFTs with stacked gate insulators are also much improved compared with those of TFTs with single-layer gate insulators.



(a)



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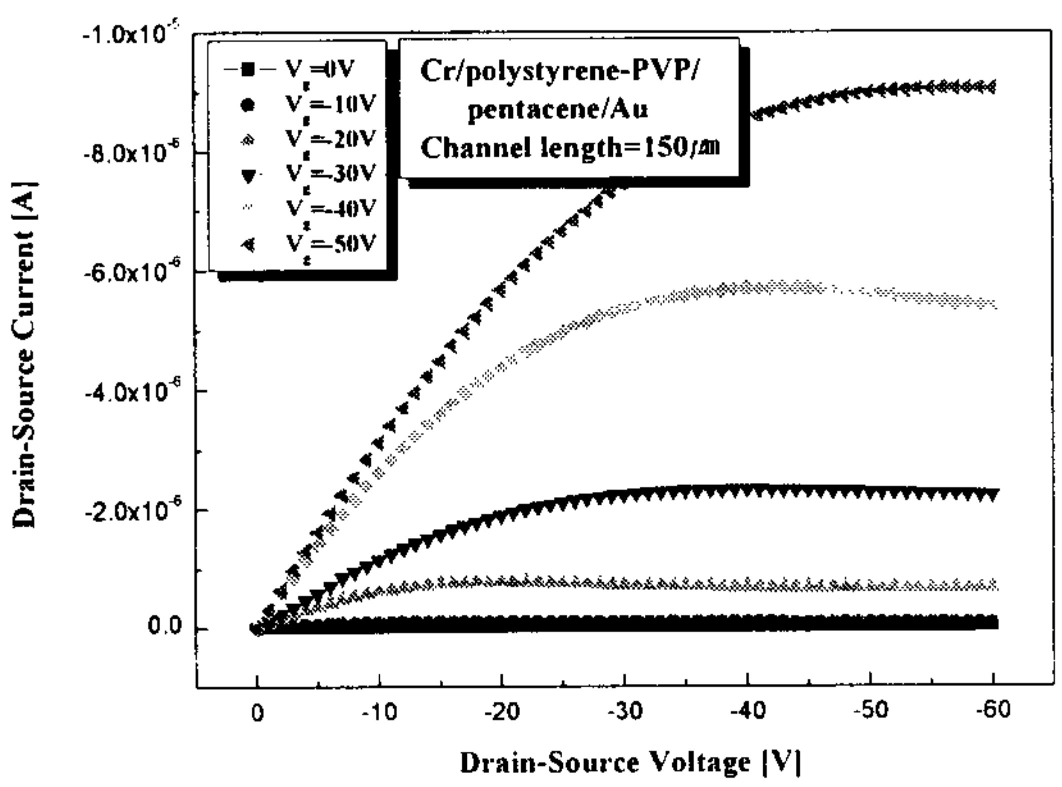
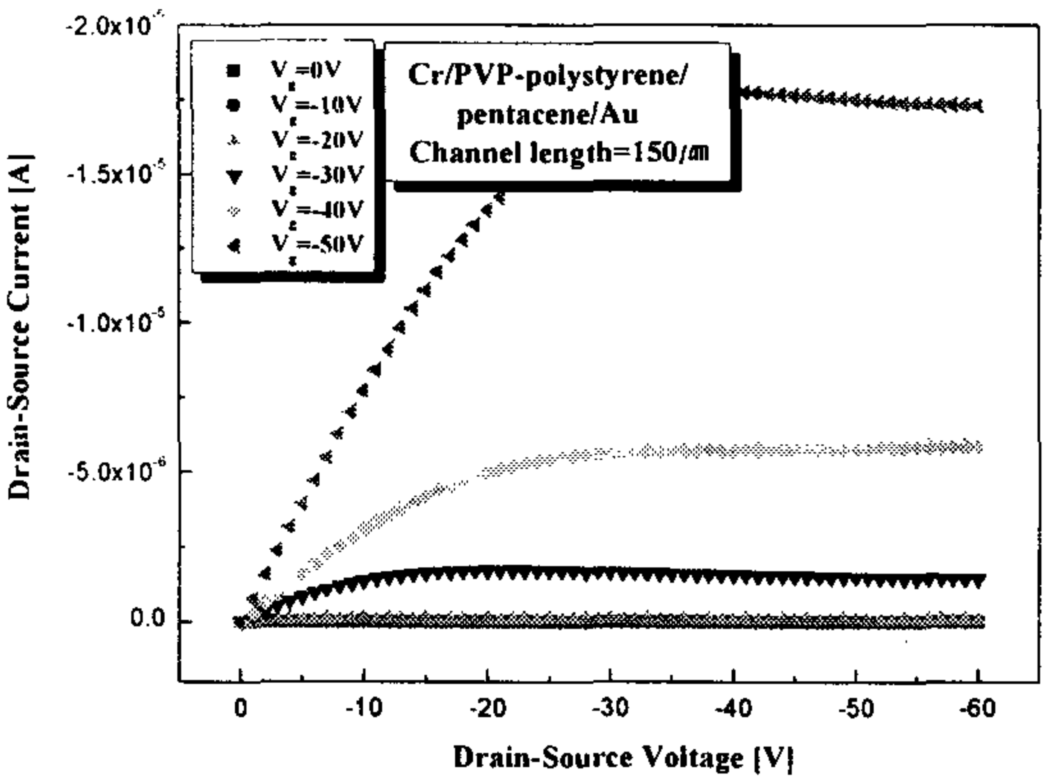
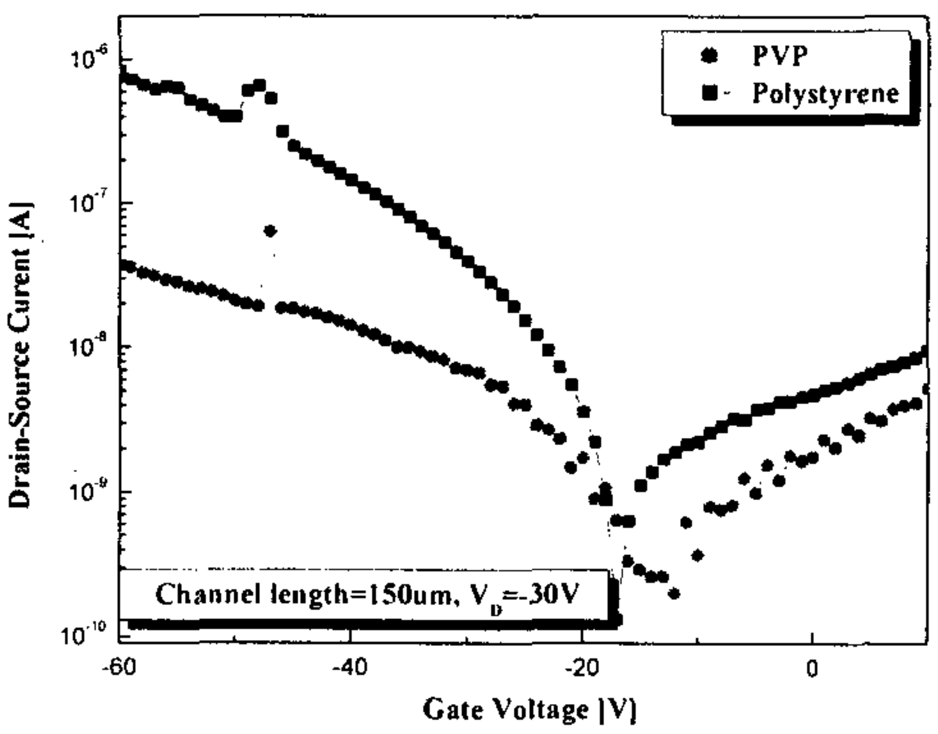


(c)

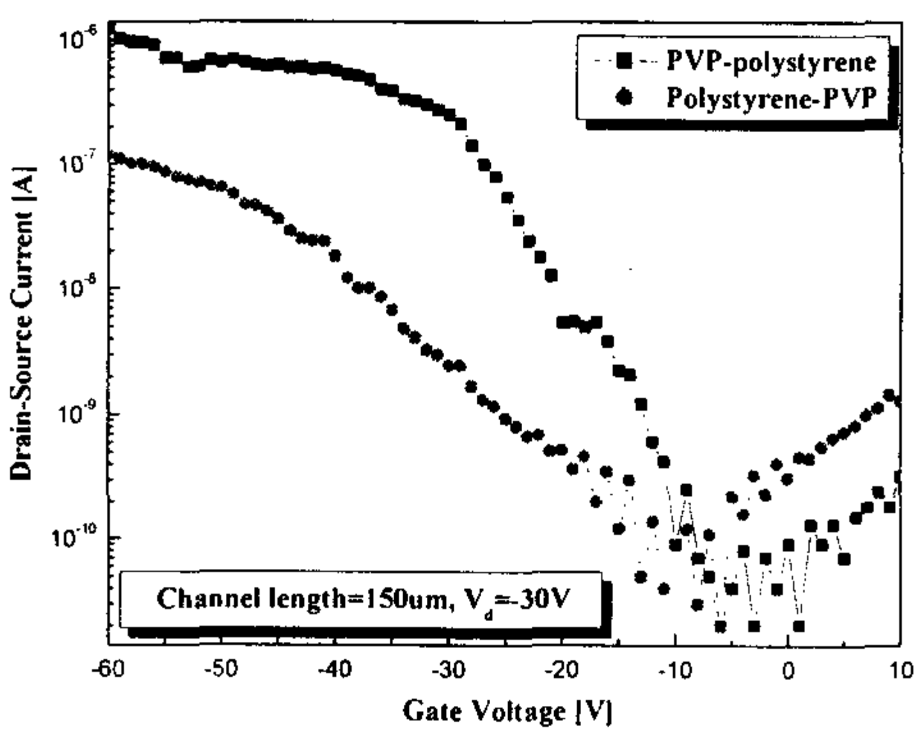


(d)

Figure 3. The output characteristics with single-layer gate insulator of (a)PVP and (b)polystyrene, and with stacked gate insulators of (c)polystyrene-PVP and (d)PVP-polystyrene.



(a)



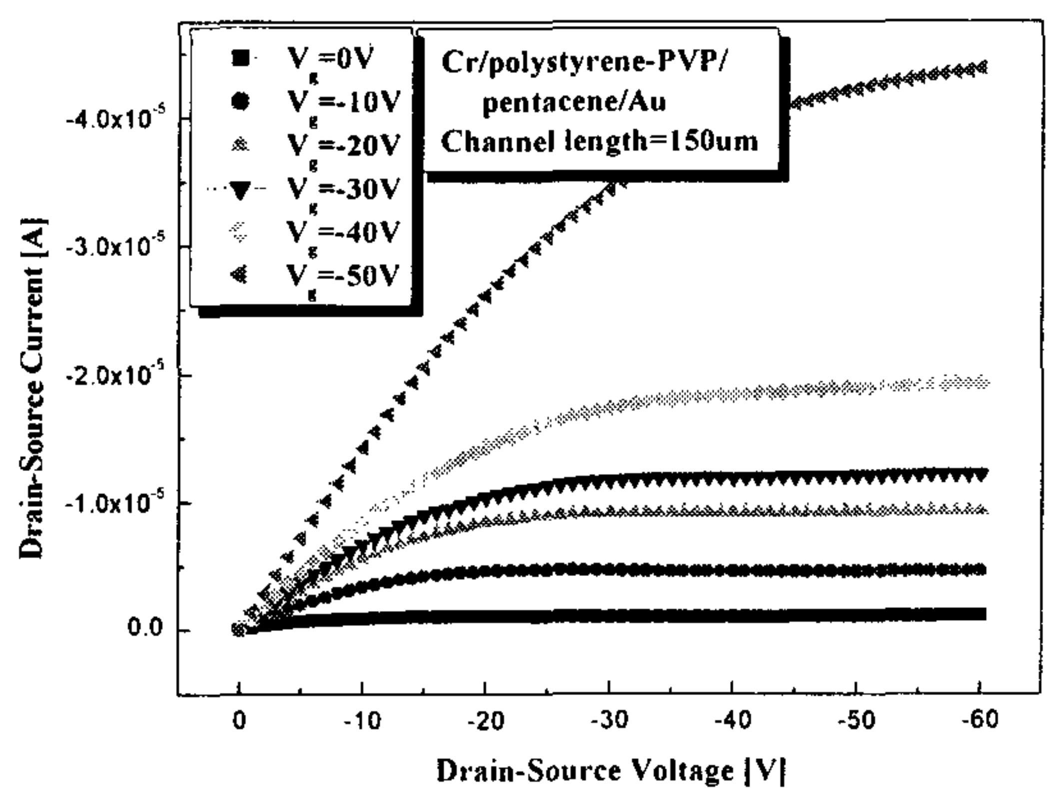
(b)

Figure 4. The transfer characteristics with (a)single-layer gate insulators and with (b)stacked gate insulators.

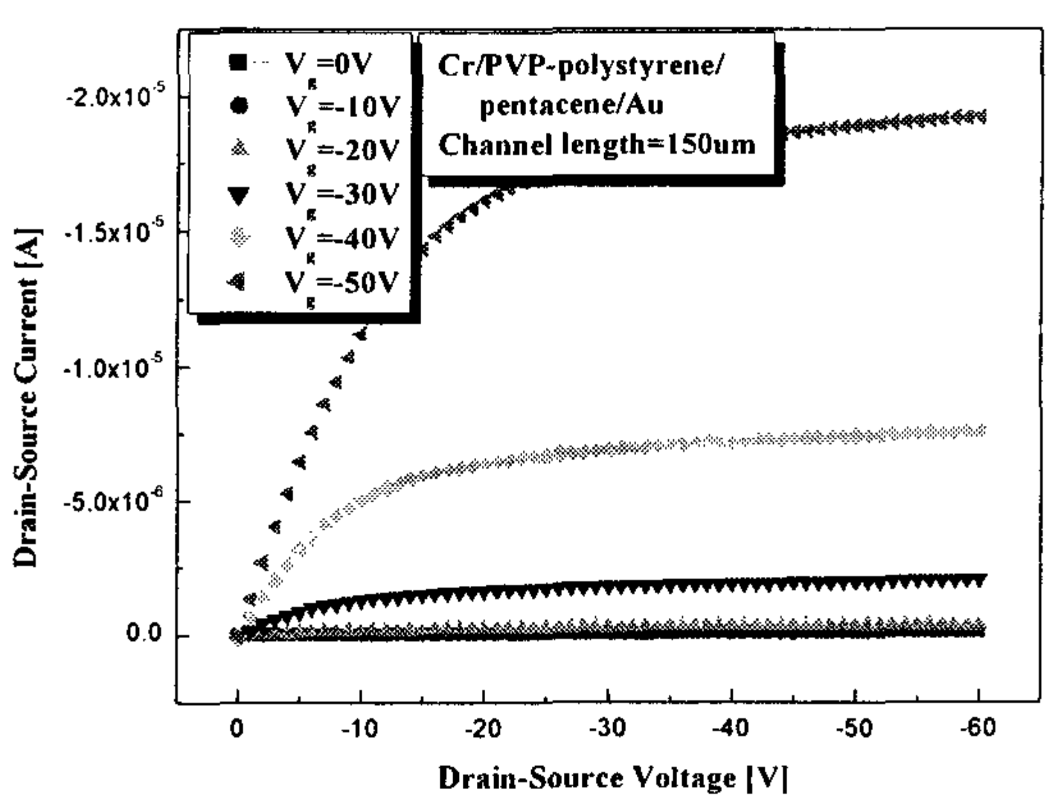
The different electrical characteristics between the two devices with stacked gate insulators are due to the different initial growth modes of pentacene layers on the gate insulators. The spin-coated gate materials can have surface undulations[4]. The surface of polystyrene-PVP gate insulator is rougher than that of PVP-polystyrene gate insulator. This roughness difference between two stacked gate insulator structures would make the growth properties of the pentacene layers on two stacked gate insulators significantly different. In order to improve the roughnesses of the surfaces of gate insulators, the process details for the gate insulator formations is adjusted as summarized in Table 2.

Table 2. The properties of spin-coating

	Speed(rpm)	Wt%	Solvent
PVP	2000	7	Ethanol
Polystyrene	2000	0.7	Chloroform



(a)



(b)

Figure 5. The output characteristics with stacked gate insulators of (a)polystyrene-PVP, (b)PVP-

polystyrene.

In figure 5, the improved output characteristics of the devices with stacked gate insulators formed by the adjusted process are presented. With the new spin coating process, not only the smoother insulator surface but also the thinner stacked gate insulators were obtained (about 450nm), which might provide the enhanced TFT output characteristics. The transfer characteristics of these devices are shown in figure 6.

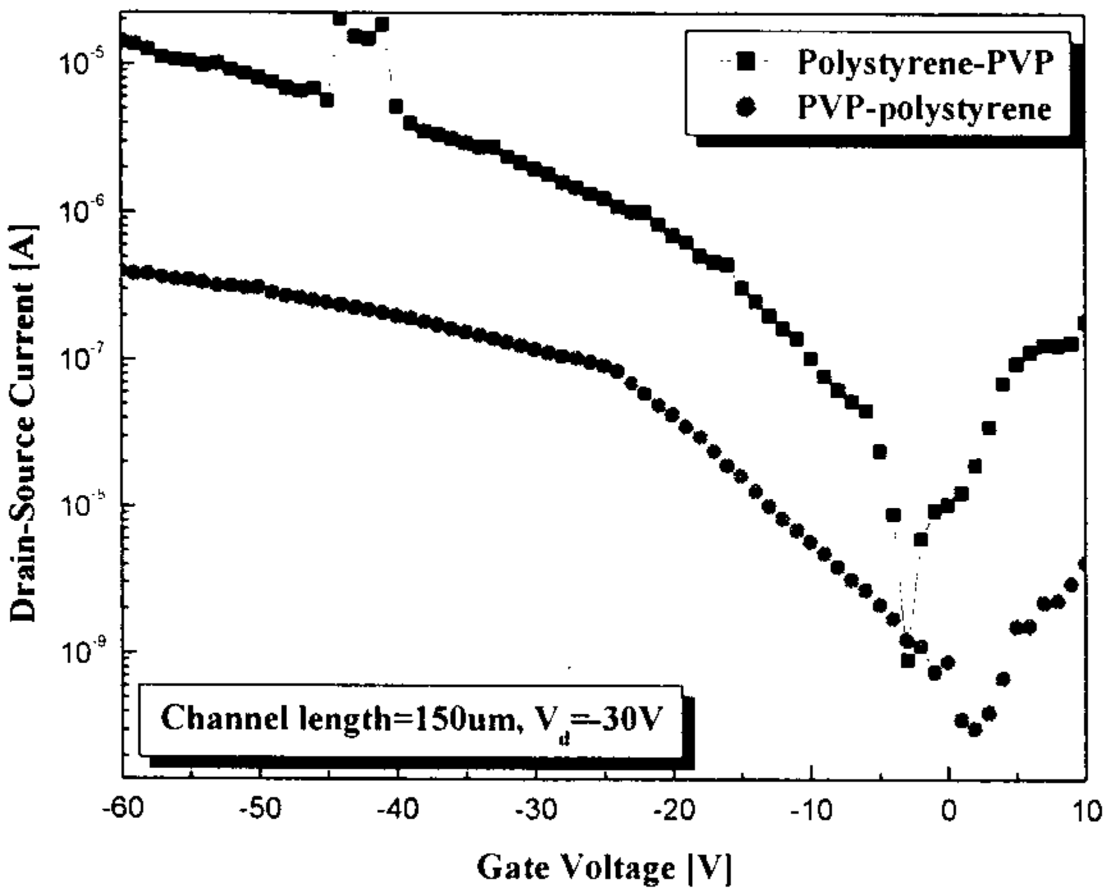


Figure 6. Transfer characteristics with stacked gate insulators by adjusted coating process.

Both on and off-current level are increased by using the thinner insulating layer and on/off current ratio is decreased slightly. The mobilities of pentacene-based TFTs with the stacked gate insulators by the adjusted coating process are improved from 0.00952 to 0.07338cm^2/Vs for the device with PVP-polystyrene gate insulators and from 0.00085 to 0.00165cm^2/Vs for the device with polystyrene-PVP gate insulators, which is mainly caused by the smoother gate surfaces and thinner gate insulator. In table 3, the on/off current ratios, threshold voltages and mobilities of the devices with various gate insulators are compared.

Table 3. The on/off current ratios, threshold voltages and mobilities of the devices with various gate insulators

Gate insulators	On/off ratio	Threshold voltage [V]	Mobility [cm^2/Vs]
PVP	10^2-10^3	-5V	0.00008
Polystyrene	10^4	-15V	0.00615
PVP-polystyrene	10^5	-24V	0.00952
Polystyrene-PVP	10^4	-13V	0.00085
Adjusted PVP-polystyrene	10^4	-5V	0.07338
Adjusted polystyrene-PVP	10^3	-3V	0.00165

4. Conclusions

In order to improve the characteristics of pentacene TFTs, the stacked organic gate dielectrics were adopted. The stacked PVP-polystyrene and polystyrene-PVP gate insulators enhanced the characteristics of the pentacene TFTs. As a result, the stacked organic gate insulators using different materials improve the whole characteristics of the pentacene-based TFTs. Moreover, to obtain further characteristic improvement of pentacene-based TFTs with stacked gate insulators, proper selection of the PVP solvent and the wt% of PVP and polystyrene for spin coating are achieved.

5. References

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