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Low-Frequency Noise Characteristics of Metal-Organic-Metal Ultraviolet Sensors

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Abstract

The metal-organic-metal (MOM) ultraviolet (UV) sensors with the m-MTDATA organic layer were successfully fabricated and their low-frequency noise characteristics were also analyzed. It was found that the UV-to-visible rejection ratio of the fabricated sensor was about 28.1 when biased at 5 V with a cutoff at 220 nm. With an incident light wavelength of 220 nm and an applied bias of 5 V, it was found that measured responsivity of the sensor was 2.09×10^{-4} A/W. Furthermore, a lower noise level and a larger detectivity can be obtained by using m-MTDATA based UV sensors.

1. Introduction

Research in organic photoelectric devices is now leading to advanced in many electronic and optoelectronic devices. Applications such as organic light emitting diodes, organic photovoltaic cell, organic thin film transistors, and a variety of organic sensors are the focus of intense study. Such devices have attracted both academic and industrial researchers due to their low cost, low temperature processing, and mechanical flexibility. Among them, many researchers are much attentive to the fabrication and investigation of organic sensors. As clearly reported in some review papers, the vertical organic sensor has been extensively studied, while, on the other hand, only a limited number of investigations deal with the lateral organic sensors [1, 2]. It offers some advantages in excess of the vertical one. Such as the electrodes were not in the optical path of the signal, and consequently are not demanded to be transparent [2]. Furthermore, the integration of lateral organic sensors with organic thin film transistor will be much facilitated [3]. In this study, the lateral metal-organic-metal (MOM) organic ultraviolet (UV) sensor was fabricated using 4, 4′, 4″ -tri-(2-methylphenyl phenylamino) triphehylaine (m-MTDATA) as the organic active layer. The m-MTDATA was used as the donor material owing to it has a relatively high hole mobility of 3×10^{-5} cm^2/Vs with an ionization potential of 5.1 eV and a very low electron affinity of 1.9 eV [4]. In this study, we first developed the fabrication process and analyzed the characteristics of m-MTDATA-based MOM UV sensor. The optoelectronic and noise properties of the organic sensor will be also discussed.

2. Experimental

To fabricated the samples used in this study, Si substrates were first cleaned with acetone, isopropyl alcohol, and de-ionized water followed by baking at 110 ℃ for 5 min. Then, the 80-nm-thick m-MTDATA layer was thermally evaporated on the substrate by a thermal evaporation system. Subsequently, the 60-nm-thick Al film was thermally evaporated onto the m-MTDATA layer to serve as the contact electrodes. The contacts of the device form two interdigitated, fork-shaped electrodes. The fingers of the contact electrodes were 65 μm wide and 1115 μm long with a spacing of 85 μm, and the active area was 2915×2300 μm^2. Figure 1 shows the schematic diagram of the fabricated m-MTDATA organic UV sensors. An Agilent E5270B semiconductor parameter analyzer was then used to measure the current-voltage (I-V) characteristics of these photodetectors both in the dark and under illumination. The photocurrents and spectral responsivities measurement of the organic UV sensors were measured using a 300 Watt xenon arc lamp and a calibrated monochromatic device as the light source. The low-frequency noise was subsequently carried out using a SR570 low-noise current preamplifiers with a Agilent 35670A dynamic signal analyzer.

3. Results and discussion

Fig. 2 shows the current-voltage (I-V) characteristics of the fabricated m-MTDATA organic UV sensors measured in the dark and under UV illumination. Under an applied bias of 5 V, the leakage current and photocurrent of m-MTDATA organic UV sensor were 2×10^{-12} and 4.6×10^{-10} A, respectively. The photocurrent to dark current contrast ratio of the fabricated UV sensor was 230. Fig. 3 shows the responsivity of the m-MTDATA organic UV sensor under various applied biases. It should be noted that the photo responses were relatively flat in the short-wavelength region, whereas the cutoff occurs at approximately 220 nm. With an applied bias of 5 V and incident light with the wavelength of 220 nm, it was found that measured responsivities of the fabricated m-MTDATA organic UV sensors was approximately 2.09×10^{-4} A/W. The UV-to-visible rejection ratio as the responsivity measured at 220 nm divided by that measured at 320 nm. According to this definition, the UV-to-visible rejection ratio was approximately 4.75, which could be achieved at a bias of 5 V. The m-MTDATA material could adsorb and generate the photocurrent when the photo energy exceeded the bandgap. Fig. 4 shows the noise power density spectra measured from the fabricated sensor in the frequency range from 1 to 1000 Hz. The resulting spectra measured from the sensor could be fitted reasonably well with the following Hooge-type equation [5]. With the increase in applied bias voltage from 1 to 5 V for the step of 1 V. At a 1 V applied bias, it was found that the noise power density measured from the fabricated m-MTDATA organic UV sensors was approximately 2.7×10^{-29} A^2/Hz. The total square noise current could estimate by integrating $S_n(f)$ over the frequency range for a given bandwidth B [6].

$$< i_n >^2 = \int_0^B S_n(f)df = \int_0^1 S_n(1)df + \int_1^B S_n(f)df$$
$$= S_0[\ln(B) + 1] \quad (1)$$

This study assumes that $S_n(f) = S_n(1\ Hz)$ when $f < 1$ Hz. Thus, the noise equivalent power (NEP) can be expressed as

$$NEP = \frac{\sqrt{< i_n >^2}}{R} \quad (2)$$

Where R is the responsivity of the UV sensors. The normalized detectivity (D^*) could then be determined by

$$D^* = \frac{\sqrt{A}\sqrt{B}}{NEP} \quad (3)$$

where A is the area of the sensor and B is the bandwidth. Fig. 4(b) shows NEP and D* as functions of the applied bias when B = 1 kHz. With 1 V applied bias, it was found that NEP and D* for the m-MTDATA organic UV sensor were 5.16×10^{-16} W and 1.59×10^{14} $cmHz^{0.5}W^{-1}$, respectively. These values indicate that a lower noise level and a larger detectivity can be obtained by using m-MTDATA based UV sensors.

4. Conclusions

In summary, m-MTDATA organic UV sensors were successfully fabricated and characterized. The proposed sensor with the use of m-MTDATA material has the small dark current, large photocurrent to dark current contrast ratio, and high UV-to-visible ratio. Furthermore, we substantially reduced noise equivalent power and enhanced detectivity using m-MTDATA active layers.

References

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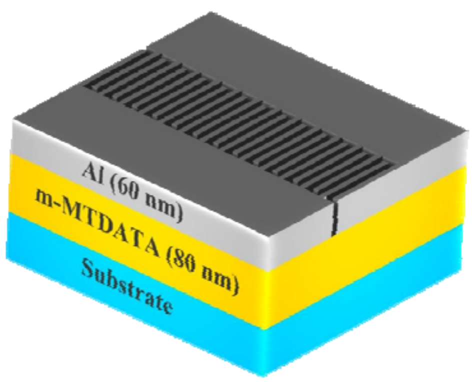

Fig. 1 Structure of the m-MTDATA organic UV sensor.

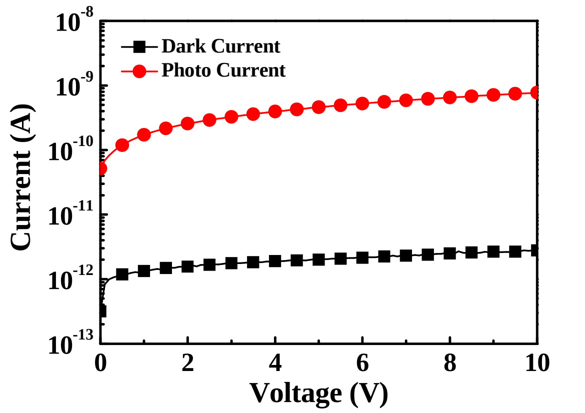

Fig. 2 I-V characteristics of m-MTDATA Organic UV sensor.

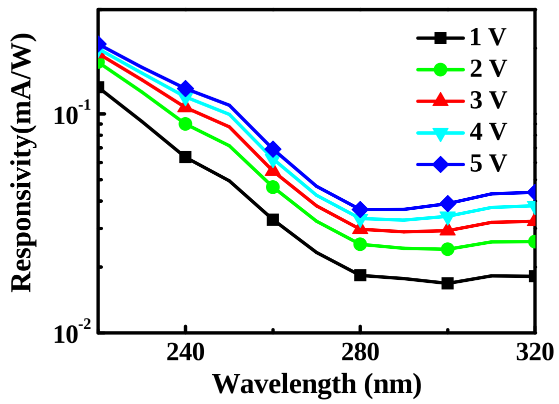

Fig. 3 Spectral responses of m-MTDATA Organic UV sensor.

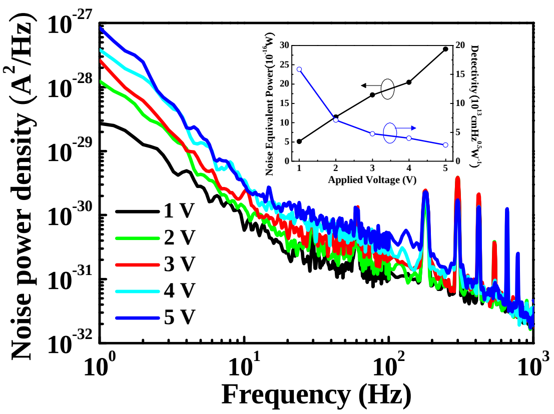

Fig. 4 Noise power density spectra of the m-MTDATA Organic UV sensor operating under applied biases. The inset is noise equivalent power and normalized detectivity of this sensor.