

Fabrication and Characterization of CuPc Thin Film-Based Organic Field-Effect Transistor (OFET) for CO_2 Gas Detection

Sujarwata[1,2*], Kusminarto[2], Kuwat Triyana[2]
[1]Physics Department, Semarang State University, Jl. Sekaran, Gunungpati Semarang 50229, Indonesia
[2]Physics Department, Gadjah Mada University (UGM), Jl. Bulaksumur, Yogyakarta 55281, Indonesia
* E-mail of the corresponding author: sjarwot@yahoo.co.id

Abstract

Fabrication and characterization of OFET with bottom-contact structure and channel length of 100 μm was carried out for detecting CO_2 gas. The OFET fabrication was done by, firstly, blenching the substrate with ethanol in an ultrasonic cleaner. It was, then, followed by the deposition of source and drain electrodes on the substrate by implementing a vacuum evaporation method and lithography technique. The CuPc thin film deposition between source/drain was, then, carried out. The characterization result showed that the active region of V_D was (2.80 - 3.42) V and the current I_D was (0.00095 - 0.00169) A. The fabricated OFET was tested to detect CO_2 gas. Its response time and recovery time was found to be gas 60 s and 50 s respectively.
Keywords: deposition, CuPc, thin film, channel length, lithography

1. Introduction

Phthalocyanine semiconductor materials and alloys have commercial potential aspects and offer a superior application compared to silicon. Phthalocyanine shows high sensitivity to electron acceptor gas and thin film surface absorption followed by charge transfer reaction (Zhou et al, 1996). This reaction affects the charge carrier and an increase in conductivity. Research conducted by Mirwa et al (1995) indicated that phthalocyanine is a complex metal suitable to be used as a gas sensor instrument and to detect NO_2 gas.

Recent studies show that organic substances of phthalocyanine material in the form of a thin film are used as the active layer of the gas sensor. The electronic properties of thin films of phthalocyanine metal (MPc) are influenced by foreign gas (Toshihiro et al, 2003). MPc is an organic semiconductor material that has a high sensitivity toward NO_2 gas. The most widely used method of MPc thin film deposition is the high vacuum evaporation (Maggioni et al, 2005). The sensitivity of the CuPc thin film is very high when detecting NO_2 gas, but its response time is slow. Time to reach 90% saturation value with a concentration of 500 ppm at room temperature is 6 minutes (Chakane et al, 2012).

Sensitivity of gas sensor with NO_2 doping and cooling temperature of 770 K in liquid nitrogen, has been studied for room temperature operation (Roto et al, 2000). Pretreatment with NO_2 showed an increase of sensor sensitivity with two changes of magnitude conductivity and increase of recovery time. The weakness of this study is the difficulty to control the NO_2 doping, causing damage to the edge of the thin film surface and change of the dynamic conductivity. The CuPc thin film gas sensor has high sensitivity at a substrate temperature of 170 ^oC and 475 ^oC with a thin film thickness of 50 nm. This condition was found when detection carried out with gas concentration of 0.18 ppm Cl (Toshihiro et al, 2003).

2. Method

The CuPc thin film-based OFET scheme is shown in Figure 1. This study used CuPc material (copper phthalocyanine) as the OFET active layer. The active layer was deposited on SiO_2 with vacuum evaporation method (Model JEOL JEE-4X) at room temperature. The OFET fabrication used bottom contact structure with the drain (*D*) electrode distance to the source (*S*) was defined as *L* and the width of each drain and source was W. The OFET fabrication stages were started by blenching the substrate with ethanol and water in a bath ultrasonic cleaner for 60 minutes. It was, then, followed by deposition of *S* and *D* using Au and, finally, it was ended by the deposition of the gate (*G*). The depositions of *S, D* and *G* on the Si/SiO_2 was done by implementing lithography. The thin film deposition pressure was examined as 8.10^{-4} Pa during four hours and the evaporation vacuum current was 45 A. Result of I-V measurement was used for OFET characterization. The next step was OFET performance test for detecting CO gas, including response time and recovery time.

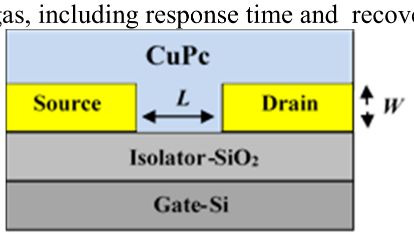

Figure 1: CuPc thin film-based OFET scheme

3. Result and Discussion

OFET has been successfully made by using a vacuum evaporator with 8.10^{-4} Pa pressure and currents of 45 A for 4 hours at room temperature. OFET fabrication process aimed for application of CO_2 gas sensor at room temperature as shown in Figure 2. The OFET was placed on the PCB using gold wire and silver paste to facilitate experiment. OFET resistance contact was, then, installed with cable for doing the experiment (Figure 3).

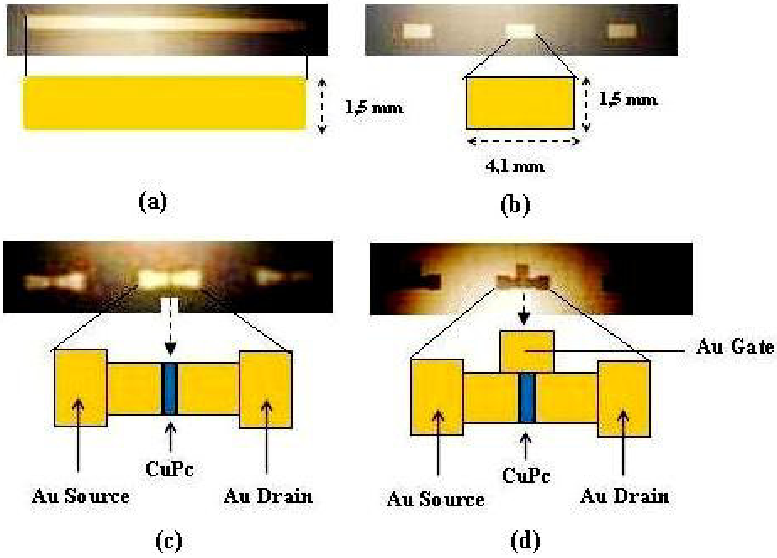

Figure 2. OFET fabrication process: (a) Au deposition on SiO_2 substrate, (b) source/drain electrode, (c) patterned source and drain electrode, (d) patterned source, drain and gate electrode.

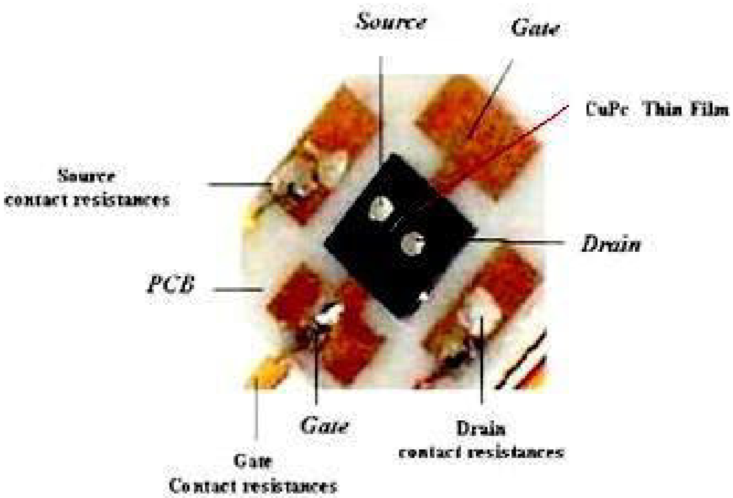

Figure 3. Result of OFET fabrication on PCB

Figure 3 shows the result of the OFET fabrication with bottom contact structure and the channel length of 100 µm for detecting CO_2 gas. The OFET components consisted of two contact resistances (drain and source) and coated with organic semiconductor that is sensitive to CO_2 gas. Gate was printed onto a substrate (Si/ SiO_2) on the bottom (bottom gate). Gas sensor does not require a heater for detecting CO_2 gas, because it operates at room temperature. The OFET has the following specifications: channel length (L) of 100 µm, channel width (W) 1 mm, dimension 4.1 mm x 1.5 mm, bottom-contact configuration, room temperature operation, and the operating voltage of 3 V - 4 V. Figure 4 shows the OFET characteristics for gate voltage variation (V_G) of (-3 to 3) V.

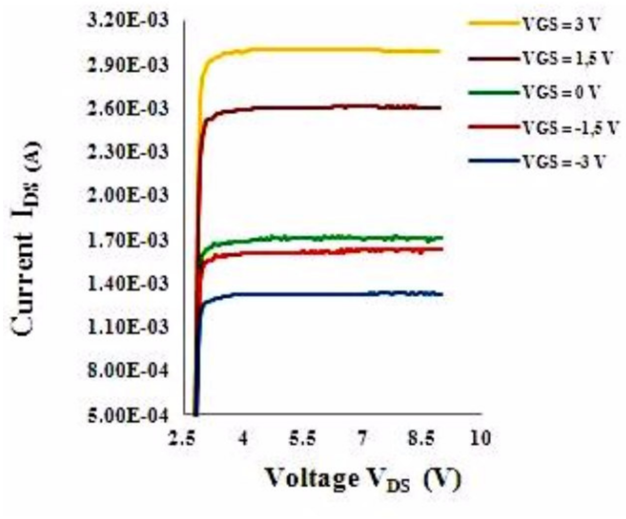

Figure 4. OFET characteristics

The OFET characteristics shown in Figure 4 expresses that the active region of drain voltage (V_D) is 2.79 V - 3.43 V and drain current (I_D) is 0.00095 A - 0.00109 A. The OFET saturation region of drain voltage V_D is (3.43 - 9) V, this region is called cut off area. The OFET operates optimally at a voltage of 2.80 V - 3.42 V. The increase in the value of V_{DS} will cause the increase in current I_D up to the saturation point of the transistor. If V_{DS} depletion region is increasing, there will be a cut-off voltage conditions (V_P). The V_{DS} voltage that causes the cut off is called cut-off failure, despite an increase in the value of V_{DS}. The OFET drain current (I_D) at that time is a maximum drain current (I_D), which is achieved when V_{GS} = 0 V and $V_{DS} > |V_P|$. At the cut-off area I_D has a fixed value, so OFET can not respond to gas. The OFET detects gas in the active area, in which the I_D current change will alter V_{DS}.

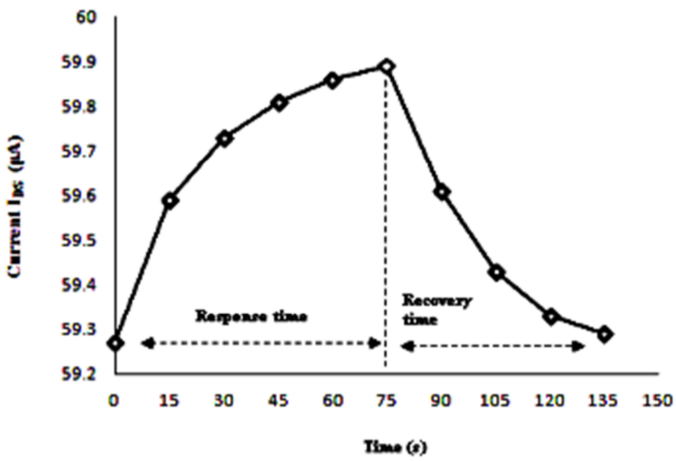

Figure 5. OFET response to CO_2 gas

The OFET performance characterization test with test gas (CO_2) was observed for every 15 seconds and the current flowing S to D was, then, measured. OFET response to CO_2 gas test with a volume of 0.5 cc is shown in Figure 5. Gas sensor (OFET) will exhibit certain properties when it is subjected to gas or when the gas sensor is kept out of gas. Sensor resistance will decrease rapidly when the sensor is subjected to the gas and when it is kept out from the gas, the resistance will back to its original value. An event of a decrease in resistance of gas sensor subjected to gas is called a response time and an event when the resistance is back to the original value is called a recovery time.

Response time is required by the sensor to recognize a detected gas, while the recovery time is the time taken by the sensor to return to the normal position. The response time is the time to reach 80% of the maximum current and the recovery time is the time to release 80% of the maximum current (Liu et al, 1996). Based on the theory of Liu (1996), the response time and recovery time can be defined (Figure 5). Figure 5 shows the response time and recovery time of the OFET to the CO_2 gas, those are 60 seconds and 50 seconds respectively.

4. Conclusion

CuPc-based thin film OFET has been made by implementing a vacuum evaporation method at room temperature having an active region of 2.80 V - 3.42 V. The OFET size is 6.15 mm^2 and the distance between the source and the drain is 100 μm. The OFET has been tested for detecting CO_2 gas with a response time of 60 s and a recovery time of 50 s.

Acknowledgment

The authors want to thank Putut Marwoto and Sutikno from Semarang State University for their information related to lithography technique and a valuable discussion supporting this research.

References

Chakane, S.D., Datir, A.M., Ghole, V.S., 2012, Nitrogen Dioxide Sensing Characteristics of Spin Coated Unsubstituted Copper Phthalocyanine Films, *IMCS 2012-The 14th International Meeting on Chemical Sensors.*

Liu C.J., Hsieh J.C. and Ju Y.H., 1996,' Response characteristics of PbPc gas sensor: Effect of operating temperature and post deposition annealing', J. Vac. Sci. Technol. A, Vol. 14, pp. 753-756

Maggioni,G.,Quaranta,A.,Carturan,S.,Patelli,A,,Tonezzera,M.,Ceccato,R.,Della Mea,G., 2005, Deposition of copper phthalocyanine films by glow discharge-induced sublimation for ga sensing applications, *Surface & Coatings Technology 200* (2005) 476– 480

Mirwa, A., Friedrich,M, Hofman,A, 1995, *Sensors and Actuator* B24-25,596

Roto, Triyana, K. dan R. Sudirman, 2000, Pengaruh konsentrasi pembawa muatan pada laju tanggap polianilin sebagai dasar sensor gas, *Laporan penelitian Fundamental Nomor: 16/P2IPD/DPPM/VI/1999.*

Toshihiro Miyata, Seiji Kawaguchi, Makoto Ishii, Tadastugu Minami, 2003, High sensitivity chlorine gas sensors using Cu-phthalocyanine thin films, *Thin Solid Films* 425 (2003) 255-259

Zhou, R., Josse, F. , Göpel, W., öztürk‡, Z.Z. dan ö.Bekaroglu§, 1996 Phthalocyanine as sensitiv material for chemical sensors, *Applied Organometallic Chemistry*, Vol.10,557 – 577.