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An active device-JFET for sensing Jasmine aroma

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***Abstract*—** Sensing the aroma of Jasmine and evaluating its quality is an important commercial activity. Aroma of Jasmine has unique fragrance and high economic value. Assessing the quality of such aromas has created lot of interest in researchers. Use of passive sensors in E-noses for floral aroma sensing is available in literature. For the first time, an active device such as FET is tried for Jasmine aroma sensing. A junction field effect transistor (JFET) is fabricated and tested as sensor for jasmine aroma. Sensitivity of JFET to jasmine aroma is found to be 1.5 to 4 times higher than resistive film reported in literature. This paper presents method of fabrication of JFET, experimental procedure for measuring aroma of Jasmine flower, effect of operating in different regions of JFET on aroma sensing; repeatability of the sensor. The sensor developed is useful in evaluating quality of aroma of jasmine flower and to find the time at which flowers can be harvested and taken for extraction.

***Keywords*—**Aroma, Jasmine, quality, evaluation, FET, PEDOT: PSS

I. INTRODUCTION

India is native to many aromatic and medicinal plants. It is necessary to develop electronic noses for objective assessment of the quality. Though many sensors are available for sensing gases [1-3], only a few researchers have worked on building an e-nose using commercially available sensors for evaluating quality of jasmine aroma. The electronic way of assessing the quality of flowers can be used to fix fair price for flowers based on quality and give better economic returns for the flower growers, the farmers.

Jasmine, a very popular flower has strong, sweet and pleasing aroma with many chemical compounds [4], and till today no one has managed to artificially produce the natural aroma. It is an important traditional and commercial flower crop in India. Jasmine flowers release their characteristic aroma any time from late evening to early morning based on environmental conditions [5]. Flowers should be harvested when they release maximum aroma and used for extraction immediately. An extract of Jasmine aroma, the concrete, is prepared from flowers in the neighbourhood of cultivations. Further processing of concrete yields Jasmine absolute and essential oil.

Presently, evaluation of the quality of Jasmine aroma is by experienced human testers or by Gas chromatography mass spectrometry (GC-MS) [5]. Human evaluation is expensive, laborious, highly subjective, inaccurate whereas GC-MS method is expensive, time-consuming and cannot be used on fresh flowers. A sensor, which mimics mammalian olfactory system, operates faster, produce quantitative, reliable, repetitive and accurate results is the need of the hour. Use of passive sensors is common in floral aroma sensing. [6-11]. This paper presents, design and fabrication of an ***active sensor*** JFET using PEDOT: PSS (poly 3,4-ethylenedioxythiophene: polystyrene sulfonate), a commercially available, conducting polymer and its use as jasmine aroma sensor. The sensor works on the principle of change in resistance (drain current) when exposed to aroma.

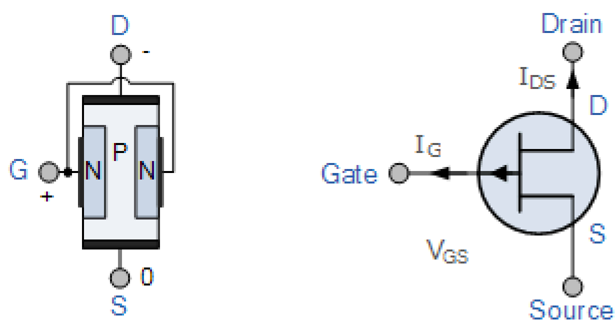
This article is organized as follows: Section I briefs about jasmine aroma, its uniqueness, need for assessing the quality of jasmine aroma, related works reported in the literature, novelty in present research work; Section II contains materials and the methods used, sensor fabrication technique, its characterization, experimental set up and procedure; Section III discusses results obtained, comparison of results with the work reported in literature, sensing characteristics of two similar JFETs when exposed to aroma, effect of different operating regions of JFET on aroma sensing, aroma variations from bud to bloomed to degraded stage, Section IV summarizes observations of experimentation, section V concludes research work with future directions.

II. MATERIALS AND METHODS

A. Sensing material

PEDOT: PSS is available as dispersion in water with conductivity grades from low to high. Heraeus Clevios™ AI 4083, a low conductivity grade PEDOT: PSS has been selected so that conductivity can be modified by doping.

B. JFET Sensor Fabrication



(a) (b)

Figure 1: P channel JFET (a) Schematic (b) Circuit symbol

Field effect transistor is a three terminal voltage controlled semiconductor device. Figure 1 shows schematic diagram and circuit symbol of JFET. Use of P-type semiconductor material in the channel (region between drain and source) makes a P type JFET. The conductivity of the channel is modulated by the gate channel junction when reverse bias is applied. This in turn modulates effective width of the channel and hence, current through the channel. Copper metal PEDOT: PSS junction/interface is a rectifying interface [12]. This property has been used to fabricate a JFET as aroma sensor. When a PEDOT: PSS sensor film is formed between two electrodes with ohmic contacts the bulk resistance of the film can be modulated using copper PEDOT: PSS rectifying interface as in other FETs. A voltage applied between one of the electrodes and the rectifying contact formed below the bulk resistance will change the resistance of the film depending on voltage applied. This principle has been applied to design and fabricate a planar JFET Jasmine aroma sensor in the present work.

A large copper area is retained on an epoxy substrate but isolated from the two electrodes as shown in Figure 2a. This copper layer serves as the gate electrode that creates a depletion layer at this interface which is modulated by the voltage applied to gate and one of the electrodes. The drain and source electrodes are abraded with pencil lead to form ohmic contacts [12]. Figure 2 shows different stages of JFET fabrication. Device specifications are: drain electrode length =18mm, width = 0.5mm, distance between drain and gate = 0.25mm, gate electrode length = 18mm, width = 8.5mm, distance between gate and source = 0.25mm, source electrode length = 18mm, width = 0.5mm.

(a) (b) (c)

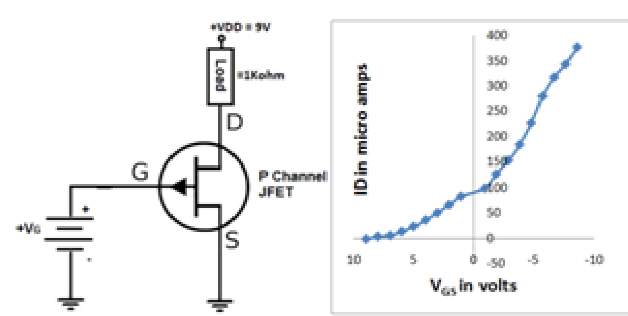
Figure 2: (a) Patterned glass epoxy substrate (b) Pencil abraded drain and source electrodes (c) Pristine PEDOT: PSS film as JFET

Copper surface on patterned glass epoxy substrates is roughened for better adhesion of film. Standard cleaning procedure are used before casting the film. The drain and source electrodes are abraded using pencil lead (Nataraj-HB). Care should be taken to ensure open circuit between drain and gate & source and gate terminals. 50µL of sonicated pristine PEDOT: PSS is taken in a micro pipette and a uniform film is drop cast over the substrate covering all three electrodes with an active surface area of 1cm^2 and dried in hot air oven at 45^{0}C for 45 minutes. Dried JFET, is shown in Figure 2c, and is used one day later to allow for stabilization of its resistance in the ambient environment. This procedure is followed for all devices used. FETs are stored in an air tight box when not in use.

C. V-I characteristics of JFET

Circuit used for studying V-I characteristics of as fabricated JFET is shown in Figure 3a and V-I characteristics of JFET are shown in Figure 3b. Gate voltage is varied from -9V to +9V using Agilent variable DC supply and voltage measurements are made across 1KΩ load resistor using GRAPHTEC- midi logger GL84 and drain current is given by:

$$I_D = (V_{Load} / 1K\Omega)\ \text{mA} \qquad (1)$$



(a) **(b)**

Figure 3: (a) Circuit for studying V-I characteristics of JFET (b) V-I characteristics of the fabricated P channel JFET

It may be observed that V-I characteristics in Figure 3b is similar to a classical P type JFET. In V-I characteristics, the region ***for positive gate voltages corresponds to reverse biased gate channel diode*** which is used for sensing Jasmine aroma.

D: Experimental set up and Procedure

Experimental setup is shown in Figure 4. All measurements use JFET sensor as well as resistive film sensor for comparing sensitivities.

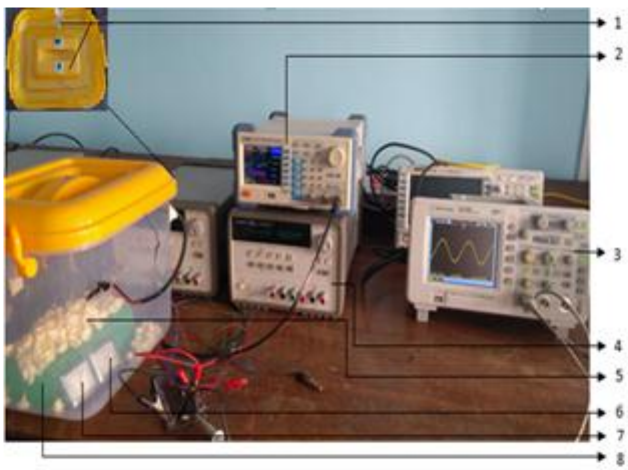


Figure 4: Experimental set up for testing FET and resistive film to jasmine aroma. (1) Sensing films-FET and resistive films (2) Signal generator (3) Digital storage oscilloscope (4) DC supply (5) Jasmine flowers inside sensing chamber (6) Humidity sensor (7) Temperature sensor (8) Perforated enclosure over the fan

Drain voltage is fixed at 9V for JFET and then gate voltage adjusted for drain current of 20µA. To compare the sensitivities of an active device JFET with a passive sensor, a resistive film as reported in literature [13] is fabricated and used in the sensing chamber. For the resistive film, a sinusoidal AC input of 3Vrms at 10KHz is applied in a potential divider circuit. Following procedure is used to conduct the experiments. i. Circuit is powered ON for 10 minutes for initial stabilization. ii. After 10 minutes changes in baseline of the sensors is recorded for next 1minute at the rate of 1sample/second. iii. 20grams of jasmine flowers are introduced into the sensing chamber. iv. Changes in drain current of FET and resistance of the film is recorded/measured for next 1minute at the rate of 1sample/second. V. Flowers are then taken out and the sensor is exposed to air for recovery. Sensor's recovery is also recorded until returned to base line value which may take anywhere from 1 minute to 5 minutes. All measurements are made at room temperature (30-35^{o}C) unless stated otherwise.

III. RESULTS

A. Response of PEDOT: PSS JFET to jasmine aroma

Figure 5 shows screen shot of voltage across load resistance of JFET when exposed to Jasmine aroma; displayed using data logger. It may be noted that change in voltage across the load resistor 1KΩ in Figure 3a is directly proportional to drain current. Red and Blue markers in Figure 5 indicate time interval of 1 minute during sensing.

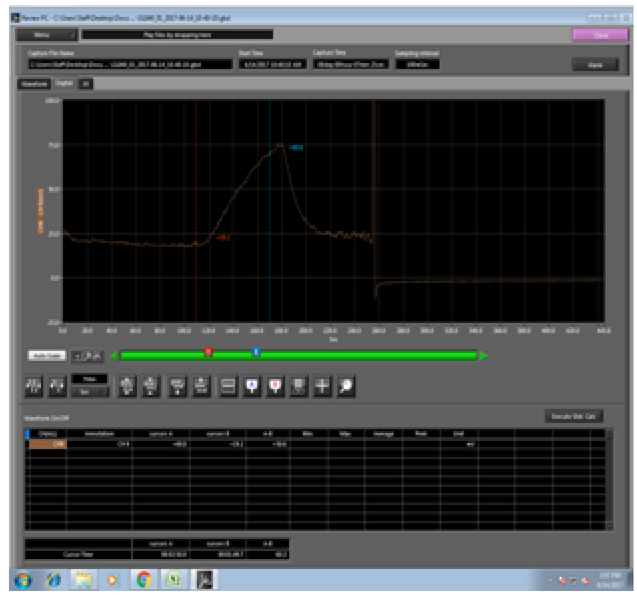
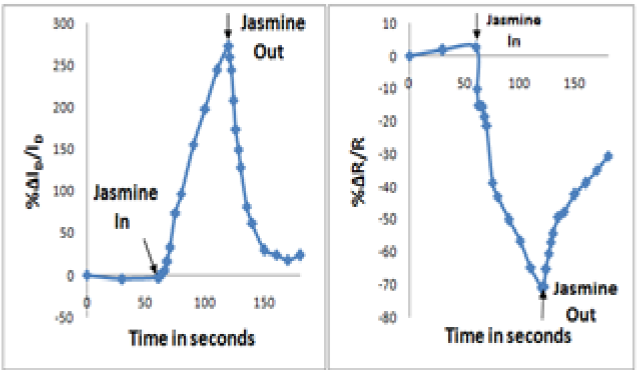


Figure 5: Screen shot of data logger when JFET is exposed to Jasmine aroma

For better visibility of response of JFET current to Jasmine aroma, variation of drain current (relative to initial current) is plotted in Figure 6a. AC measurements of resistive film are measured using Agilent DSO and plotted as shown in Figure 6b. It may be observed that change in drain current of JFET to the same Jasmine aroma is about **260**% whereas %ΔR/R of resistive film is 70%. Sensitivity of JFET sensor is **3.75** times that of resistive film for the same sample. JFET recovers in about 25 seconds whereas resistive film needs around 4 to 5 minutes of recovery time. It may also be observed that drain current in JFET increases upon exposure to Jasmine aroma, increase in drain current implies decrease of channel (PEDOT: PSS) resistance. Resistive PEDOT: PSS films also exhibit decrease of resistance of film upon exposure to aroma [13]. ***In JFET the initial resistance can be controlled by suitable bias of gate*** which modulates the thickness of depletion region.



(a) (b)

Figure 6 (a) Variation in drain current of JFET to Jasmine aroma. (b) Variation of resistance of resistive film to Jasmine aroma

B: Test for ability of two JFETs to produce same result

Two JFET sensors of approximately same initial drain – source resistance are exposed to Jasmine aroma; Figure 7 shows response of JFET sensors to Jasmine aroma. It may be observed that change in drain currents of two similar JFET sensors are nearly the same. Table 1 summarizes sensitivities of JFETs and resistive films to Jasmine aroma.

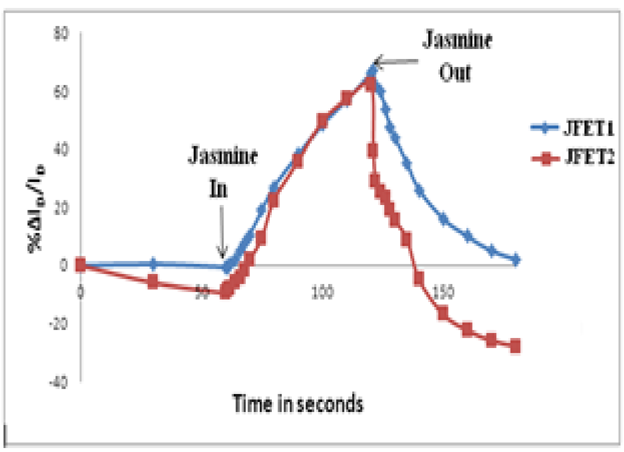


Figure 7: Response of two similar JFETs to jasmine aroma

Table 1: Sensitivities of two similar JFETs and resistive films to jasmine aroma

$\%(\Delta I_D/I_D)$		$\%(\Delta R/R)$		Remarks
JFET1	JFET2	Resistive film1	Resistive film2	
62	66	35.5	36.6	JFET is **1.8** times more sensitive than resistive film

C: Effect of operating regions of JFET on Jasmine aroma sensing

Two JFETs operating in different regions, one close to zero gate source voltage and the other close to pinch off are exposed to jasmine aroma. For JFET1 drain current I_D is adjusted to 20μA using V_{GS} = 5.5V and for JFET2 drain current is adjusted to 100μA using V_{GS} = 3V. Figure 8 shows variation in drain current of JFET sensors when exposed to Jasmine aroma. It may be observed that JFET with initial drain current 20μA is 3 times more sensitive than JFET with 100μA initial drain current.

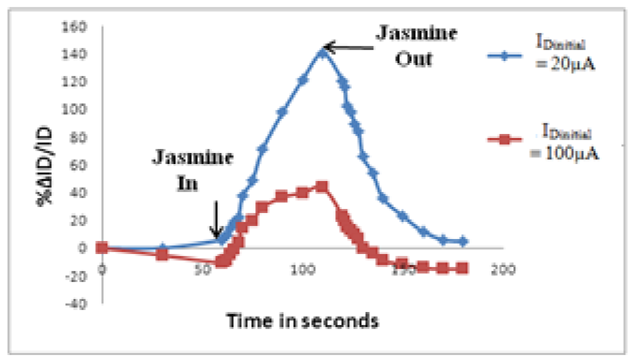


Figure 8: Response of JFET sensors operating in different operating regions to jasmine aroma

D: Variation in drain current to Jasmine aroma from bud to fully bloomed flowers and to degraded flowers

The aroma of Jasmine flower is known to peak during late evening [5]. Flowers bought from local market are tested for aroma from buds to flowers stage at different times over a period. Figure 9 shows variation in drain current of JFET sensor to jasmine aroma from buds to flowers stages. It may be observed that the aroma peaks at certain time (9-12pm). Results in Figure 9 conform to the trend shown by resistive PEDOT: PSS film [13]. Experiments are repeated to confirm this behavior and trend is repetitive (trend repeats, values may/may not repeat as the flower sample is different).

Presently, there is no standard input available as jasmine aroma against which Jasmine flowers can be calibrated. To calibrate the change in resistance to quality of aroma a reproducible standard is necessary. However, this sensor can be used as a relative standard after calibration against human evaluation.

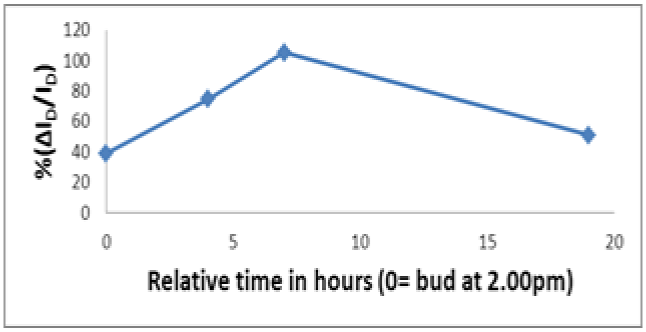


Figure 9: Variations in drain current of JFET to jasmine aroma from bud to flower to degrade stage

During all measurements relative humidity inside the test chamber is measured and found not varying during sensing time of 1 minute. Measurements under saturated environment are found to damage the sensing film hence measurements are not done under saturated conditions.

IV. Discussion of Observations

It has been observed that the sensitivity of PEDOT: PSS JFET sensor is 1.5 to 4 times more than that of PEDOT: PSS resistive sensor. This is due to the creation of large area gate channel depletion region whose width can be controlled by gate voltage. This in turn results in controllable channel resistance. It has also been observed that when operation is close to pinch off the sensitivity is maximum. This can be explained the following way:

Since, the area of the sensor is fixed; the maximum number of aroma molecules that can adsorb is limited and fixed. This means the maximum number of free charges that can be introduced is also fixed (n_{ad}). The sensitivity (S) depends on the ratio of free charges produced to already available free charges (n_0), i.e.,

$$S \propto (n_{ad} / n_0)$$

Since, n_{ad} is fixed, S is higher when n_0 is lower or the channel resistance is highest which is when operating close to pinch off. This active control is not possible in a simple resistive sensor.

V. CONCLUSIONS

An active sensor using PEDOT: PSS has been developed for sensing aroma of jasmine flowers. A simple method to fabricate an active device is demonstrated. Present work also suggests region of operation of JFET for enhanced sensitivity is suggested. Proposed sensor is an excellent active sensor of jasmine aroma with a sensitivity of 1.5 to 4 times compared to resistive film sensor. The Sensor developed is useful to determine the time at which aroma release by Jasmine is maximum and can be taken for extraction. The sensor developed is also useful for fixing fair price for jasmine flowers from aroma perspective. Effect of AC input on performance of the sensor may be carried out in future explorations. Sensor output may be interfaced to a microcontroller for further processing and to develop a portable device.

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Authors Profile

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