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# Effect of dye concentration on the band gap of PVA turmeric composite film

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In this work we have prepared and compared the performances of turmeric dye based herbal diodes for different dye concentrations. The diodes are prepared by sandwiching turmeric dye layer in between the Cu and Al electrode. The Cu and Al electrodes are considered as anode and cathode terminals. We have measured forward and reverse biased I-V characteristic. Asymmetric nature in current voltage (I-V) relation confirms the diode characteristics of the devices. We have also measured the rectification ratio. We have also investigated the variation of current with temperature (I-T) to test the semiconducting properties of the devices. We have observed the I-T curve and found that current increases with temperature. Data is fitted to estimate the energy of the band gap of the diode. Band gap of the diode varies with the concentration of dye. Value of the band gap decreases with increasing the dye concentration. In our experiment the maximum and minimum value of the band gap is 3.36 eV and 2.82 eV for 5% and 20% concentration of the dye solution. We have also estimated ideality factor of three cells. The findings of this work are important to develop herbal dye based electronic device.

Keywords: Turmeric dye, Cu/turmeric/Al, dark I-V characteristic, ideality factor, band gap energy.

## Introduction

Recently optical and electronic properties of different herbal dyes are being studied to develop different electronic devices. These herbal dye based device have many advantage. The herbal dye based devices are nature friendly, biodegradable and also cost-effective. There are also varieties of dyes to study. Natural dyes like turmeric, *Hibiscus rosasinesis, Sesbania grandiflora* are used as photosensitizers due to its large absorption coefficient in the visible region in dye sensitized solar cell[1–3]. But there is not much report on the semiconducting properties of turmeric dye based herbal diode and the variation of its band gap with concentration of dye.

The conductivity in herbal dye will open a new dimension in material science. It is expected that conductivity of herbal dye would be same like other different organic dyes and polymers which are often used for different electronic and photovoltaic devices. It can be prepared over a large area on various substrates from its solution by different techniques like spin-coating, sol-gel, solvent casting, sublimation, dip coating etc.

Among the others herbal dye the turmeric is easily available and cheapest natural dye. It is nothing but a powder form of rhizome of natural plant named *Cucurma longa* L. It is used in curries for flavouring and colouring of the diet. It is also used in medicine for treatments of inflammation, skin wound and cough. Now a day research workers has shown its anticancer properties. Khalil Ebrahim Jasim, Seamas Cassidy has reported curcumin (Pigment of turmeric) dye sensitized solar cell performance[4]. But the semiconducting property of this dye is still unknown.

In this work we have studied the semiconducting property of turmeric dye by varying its concentration. We have prepared turmeric dye based diode. By studying the diode characteristic the band gap has been measured. Chemical composition of turmeric dye is shown in Fig. 1. Its chemical formula is $C_{21}H_{20}O_8$. The melting point is 183°C.

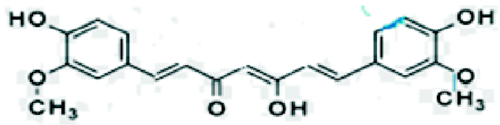


**Fig. 1.** Structure of turmeric dye.

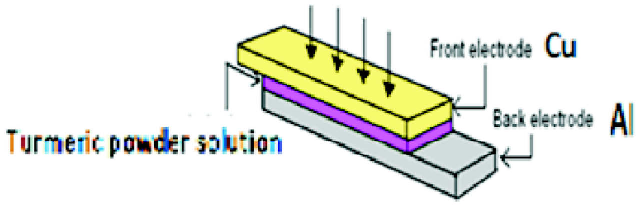



**Fig. 2.** Cu/turmeric dye/Al cell diagram.

The basic structure of the herbal dye is amorphous and disorder. Molecules are bonded by weak Van der Waals forces and dipole dipoles interactions. If the $\pi$ band is filled it is known as the highest occupied orbital (HOMO), and if the $\pi^*$ band is empty it called the lowest unoccupied molecular orbital (LUMO). Here we assume LUMO and HOMO are like CB and VB in case of inorganic semiconductors. When material is available in wafer form, the band gap can be determined by studying the conductivity variation with temperature by using a four probe method[7,8].

## Experimental

*Cell preparation:*

We have made three cells with different concentration. At first we have mixed 1 gm of Poly Vinyl Alcohol (PVA) with 15 ml water. Then the solution was stirred properly and prepared highly viscous and transparent PVA solution. Here PVA acts as an inert binder. This solution is divided into three equal parts each of 5 ml. Each part is kept in a pre-cleaned test tube. For preparing 5% turmeric solution 250 mg of turmeric powder is added in one of the test tube. Then the solution of the test tube stirred again with the help of magnetic stirrer. 2 ml of this semi solid is then deposited by using a spin coater on a pre-rubbing and cleaned Cu electrode with motor speed 800 rpm. Before and after deposition of Al electrode the cell was dried under vacuum ($10^{-3}$ mm) for 10 h. Cell 1 (Cu/ 5% turmeric dye/Al) is ready to measure I-V characteristic and I-T characteristic. We have prepared Cell 2 and Cell 3 by similar way taking 500 mg and 1 g turmeric powder for 10% and 20% turmeric solution. Cell diagram is shown Fig. 2.

*Measurement:*

I-V measurements were performed by Keithley 2400 source measure unit. The same measurement can also be done by using a dc supply and digital voltmeter and measurement is shown in Fig. 3.

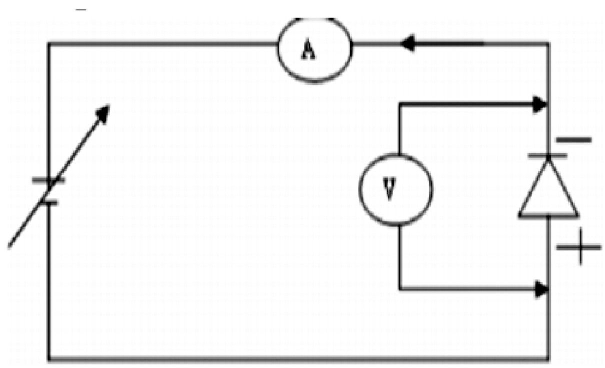



**Fig. 3.** Circuit diagram of the reverse bias connection of the diode to the Keithley 2400.

I-T characteristic is performed by using a heater with temperature controller circuit and Keithley 2400 source measure unit. Experiment is done in the temperature range 306–348 K. Heater with temperature controller circuit is designed in our laboratory. Temperature measurements were performed by a K-type thermocouple (Cromel-Allamel) with an accuracy of ± 0.15 K.

## Results and discussion

In this work we have measured current by varying voltage across the diode. Cu and Al are connected to positive and negative terminal respectively. We have plotted I-V data. I-V curve of turmeric diode is non-linear in nature (Fig. 4(a)). The current is much for 20% concentration of turmeric dye.

We have also estimated the rectification ratio (RR) as shown in the Fig. 4(b). It is shown that RR is much for 20% turmeric dye based diode.

The ideality factor ($\eta$) measures conformism of the diode to pure thermo ionic emission we have estimated ideality factor ($\eta$) from forward bias curve. Fig. 4(c) shows the loga-

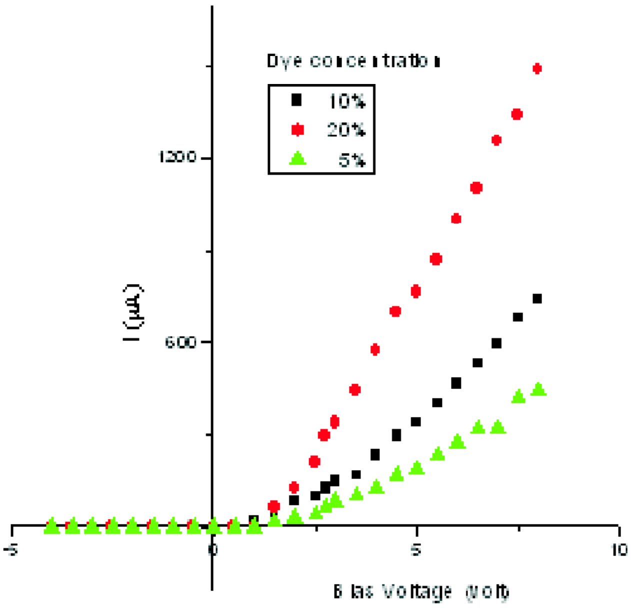



**Fig. 4(a).** Forward and reverse bias I-V curve of three turmeric diode.

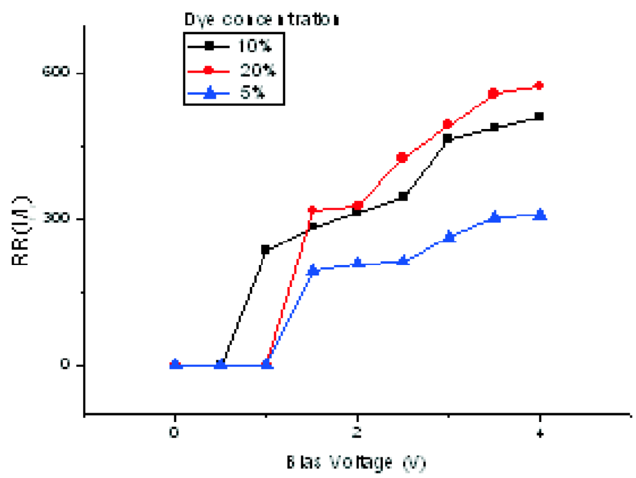



**Fig. 4(b).** Rectification ratio curves of three Cu/turmeric/Al diodes.

rithmic values of current versus voltage. Using eq. (3) ideality factor is estimated for three cells. Its values are 32.00, 38.78, and 42.19 for 20, 10 and 5% concentration respectively. Here we observed that the values of ideality factor are lower for higher concentration of turmeric dye.

It may be stated that the I-V of a diode curve may be fitted with thermionic emission (TE) theory. According to the TE theory[9,10] the forward bias I-V characteristics of a diode

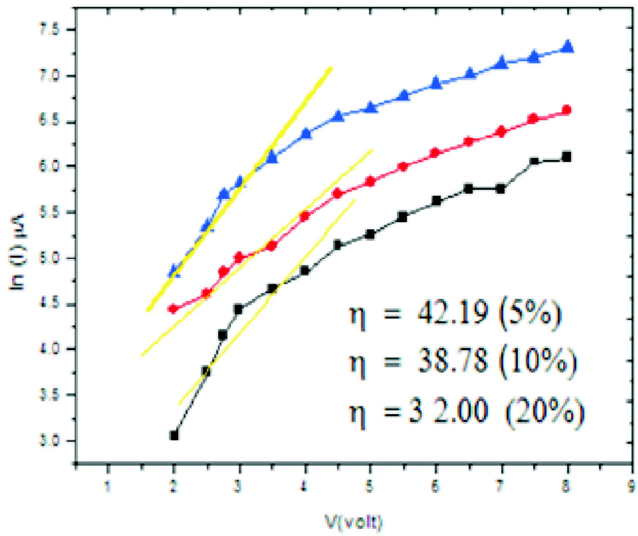



**Fig. 4(c).** ln I vs V curve for estimating ideality factor.

can be expressed as

$$I = I_0\left[e^{\frac{qV}{\eta kT}} - 1\right] \tag{1}$$

where $I_0$ is the reverse saturation current which is described as,

$$I_0 = AA^{*}e^{\frac{q\Phi_b}{KT}} \tag{2}$$

Here A and A* is the contact area and Richardson constant respectively. T is the absolute temperature and $\Phi_b$ is barrier height.

Ideality factor can be calculated from the I-V characteristic by using the following relation.

$$\eta = \frac{q}{kT}\frac{dV}{d\ln I} \tag{3}$$

By using this relation the ideality factor is estimated for three diodes which are shown in Table 1.

It may be assumed that carriers of turmeric dye are generated through the breaking of covalent bonds which require supply of energy equal to $E_g$. So it is possible to evaluate $E_g$ by studying the temperature variation of the carrier. The variation of carriers can be carried out through a study of temperature variation of reverse saturation current which is the current in the diode under reverse bias condition which is given by [11] .

$$I_0 = C\, e^{\frac{E_g}{KT}} \tag{4}$$

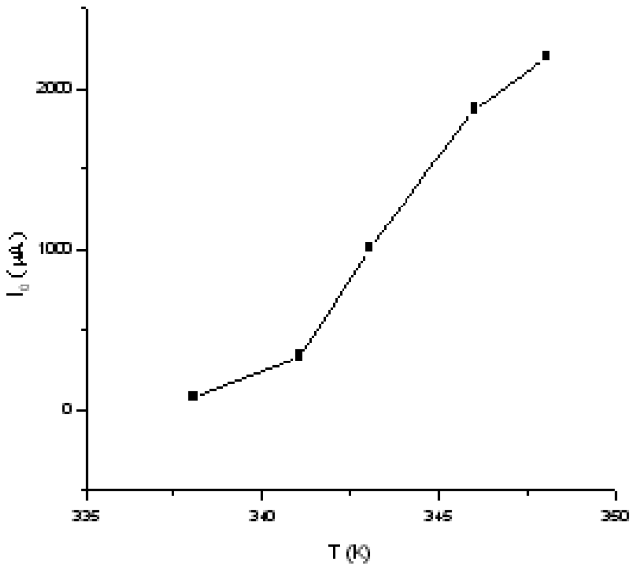
where $I_0$ is reverse saturation current, C is constant, $E_g$ is band gap, and T is temperature in K. It is seen from eq. (4) that the saturation current depends on $E_g$/kT exponentially. Taking logarithms on both sides of eq. (4) we get

$$\ln I_0 = \ln C - \frac{E_g}{KT} \tag{5}$$

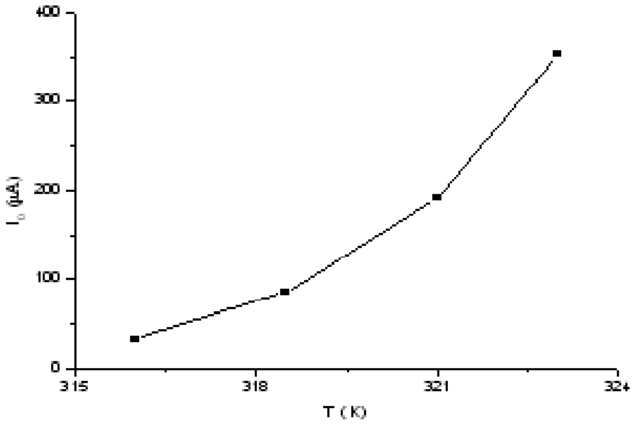
Eq. (5) implies that reverse saturation current $I_0$ in a semiconductor diode is dependent only on the junction temperature. It varies inversely with temperature. A plot of ln $I_0$ vs 1/T shown in Fig. 6 which exhibits a straight line having a negative slope. The slope gives the value of $E_g$/k. We have determined the slope (m) of the straight line and calculated the value of $E_g$. Thus

$$E_g = mk \tag{6}$$

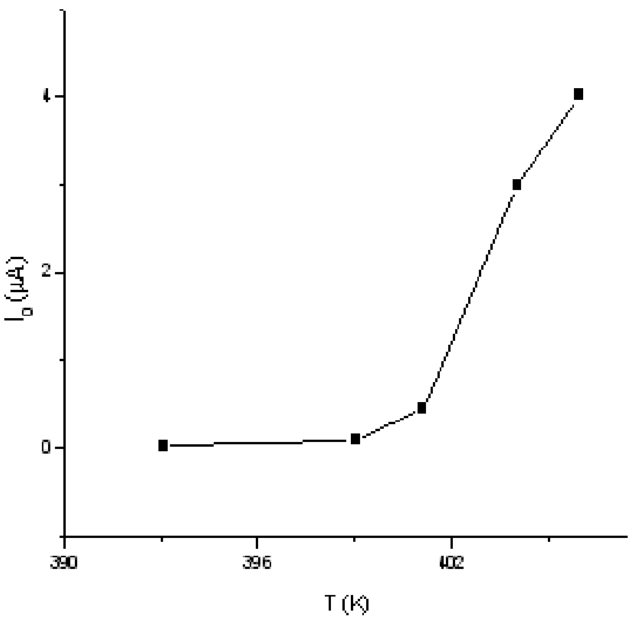
Keeping fix the reverse bias voltage across the diode I-T data is also taken using thermal bath. Here we have taken I-T data for three diodes of different concentration of turmeric dye wt. by ratio 5%, 10%, and 20%. I-T data are plotted which




(a)




(b)




(c)

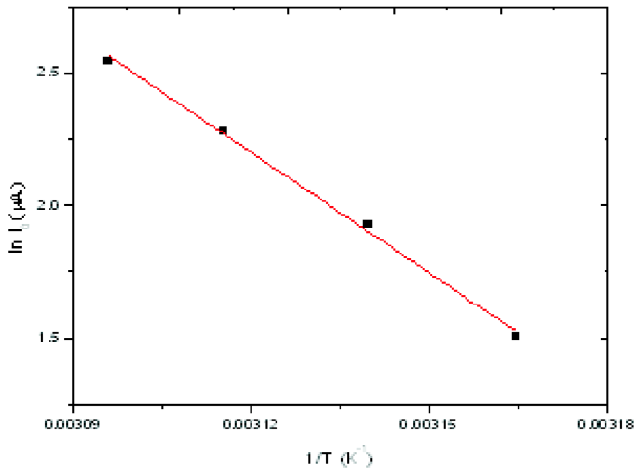
**Fig. 5.** ln I vs T curves of diodes. (a), (b), (c) are for 20, 10 and 5% concentration respectively.

are shown in Fig. 5.

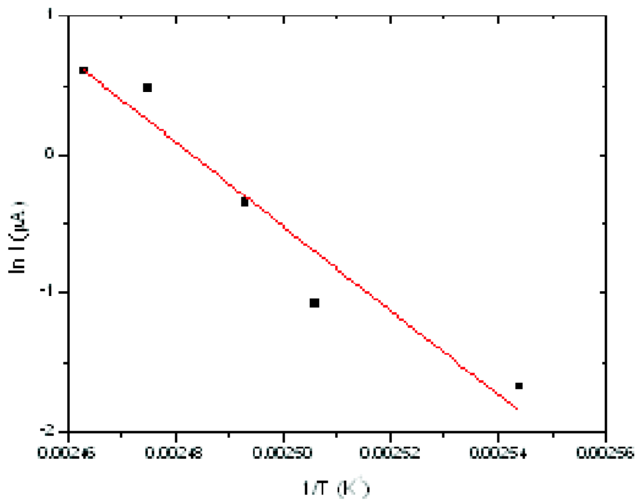
We observed that curves are non-liner in nature. Current increases with temperature and slope of the curve changes with different temperature. We have also plotted ln I vs 1/T data. Nature of curves may be considered as straight lines which are shown in Fig. 6. We have estimated band gap energy using eq. (5).

As we know, the ideality factor (η) measures conformism of the diode to pure thermo ionic emission. In our Cu/turmeric/Al system ideality factor is very high. There are various factors which may be responsible for impurity or defects of cell formation.

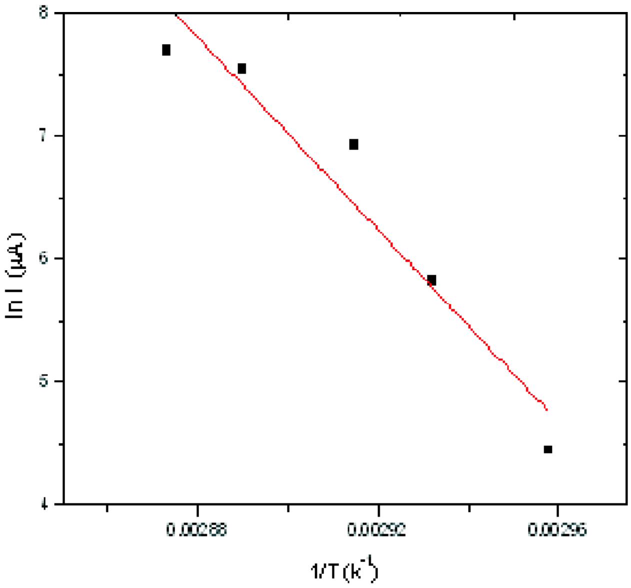
We may assume that eq. (5) is the temperature dependent current equation of the diode. The exponents can be calculated by the plot of ln $I_0$ vs 1/T for different voltage such as 2 V, 4 V, 6 V respectively. Slope of curves differ in low temperature region from high temperature. So linear fitting have been done. Though low temperature region is important for calculation of defect potential barrier, we have left this portion due to some limitations in our experimental facility. The electron concentration is essentially independent of temperature when the temperature is in the low temperature region and the activation energy of conductivity and could be related to the activation energy of mobility. But this portion is beyond our scope in present discussion.




(a)




(b)




(c)

**Fig. 6.** ln $I_0$ vs 1/KT curves. (a), (b), (c) are for 20%, 10% and 5% concentration respectively. Curves are linear in nature. Data is fitted to estimate $E_g$.

**Table 1.** Values of η and $E_g$ for different cell

| Concentration of turmeric solution weight ratio (%) | Value of Ideality factor (η) | Value of band gap (eV) |
|---|---|---|
| 5 | 42.19 | 3.36 |
| 10 | 38.78 | 2.91 |
| 20 | 32.00 | 2.82 |

Band gap of higher concentration of turmeric dye cell is low. Actual reason is still unknown. But we can assume that higher concentration of dye reduces of Gaussian density of states[15,16]. Here we assume turmeric dye is a semiconducting material and its band gap relations with free charge are given by eq. (6).

$$E_g = qV_{jc} + \left(\frac{\sigma_n^2}{2} + \frac{\sigma_p^2}{2}\right) + KT \ln\left(\frac{N_n N_p}{np}\right) \qquad (7)$$

where $E_g$ is band gap of the cell, $V_{jc}$ is junction potential in volt, q is the elementary charge, $\sigma_n$, and $\sigma_p$ is width of Gaussian density states of acceptor and donor , $N_n$ and $N_p$ is effective density of states in conduction and valance band respectively, n and p is the free electron and hole concentration. It is expected that with increasing of the dye concentration the amount of free electrons and holes concentration are also increased.

## Conclusions

In this work we have studied the semiconducting property of turmeric dye based herbal diode. Charge injection mechanism from metal into disorders herbal dye is complicated processes. Using the measurement of I-T characteristics for different concentration of dye we have shown semiconducting property of turmeric dye and also measured the band gap. The band gap varies with dye concentration. Band gap variation with concentration of dye shows that different trap level energy states. It may be caused by structural defect or impurity defect. The device may work as the herbal diode

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## References

1. K. E. Jasim, *et al., Journal of Energy and Power Engineering*, 2017, **11**, 409.
2. S. Shalin, *et al., Renewable and Sustainable Energy Reviews,* 2015, **51**, 1306.
3. G. Richhariya, *et al., Renewable and Sustainable Energy Reviews,* 2017, **69**, 705.
4. Sconza. G. Torso, *et al., American Journal of Physics,* 1994, **62(1)**, 66.
5. S. Amity *et al., Journal of Optoelectronics,* 2013, **V15(12-12)**, 1417.
6. Hue li, *et al., Scientific Reports,* 2017, **10**, 7-40134.
7. A. Holder, S. Amity and N. B. Manic, *Ionics*, 2008, **14(3)**, 263.
8. A. Halder, S. Maity and N. B. Manik, *Ionics*, 2008, **14(5)**, 427.
9. S. Maity, A. Halder and N. B. Manik, *Ionics*, 2008, **14(6)**, 549.
10. A. Halder, S. Maity and N. B. Manik, *Ionics*, 2009, **15(1)**, 79.
11. S. K. Dey, N. B. Manik, S. Bhattacharya and A. N. Basu, *Syn. Met.*, 2011, **18**, 19.
12. S. K. Dey, Md. R. Islam, N. B. Manik and A. N. Basu, *J. Mat. Sci.*, 2011, **38**, 93.
13. M. A. Lampert, *Rep. Prog. Phys.*, 2011, **27**, 329.
14. S. Antohe, L. Ion and V. A. Antohe, *J. Optoelectron. Adv. Mater.*, 2003, **5(4)**, 801.
15. S. Antohe, L. Ion and V. Rusxandra, *J. Appl. Phys.*, 2001, **90(12)**, 2928.
16. L. Ion, S. Antohe, M. Popescu, F. Searlat, F. Ionescu and J. Optoelectron, *Adv. Mater.,* 2004, **6(1)**, 113.