Organic Thin Film Transistors for Flexible Electronics

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Abstract

Progress in electronics gave rise to the concept of flexible electronics. Which are widely being used for medical and aerospace research. Further development in the fields of flexible electronics unfolded another branch of this electronics system called organic flexible electronics. Organic thin-film transistors, Organic light-emitting diodes are a few of the many forms of organic flexible electronics. Organic materials being used as the substrates increase the flexibility of the electronic circuit. The conductivity of these substrates can be controlled as per requirement by varying the doping concentration of the substrate. The cost of production of organic flexible electronics is low as compared to electronics circuits using a silicon substrate. This paper illustrates the various properties of organic materials and their applications and suitability in flexible electronics.

Keywords: organic, flexible, transistors, films.

1 Introduction

A branch of electronics, called the flexible electronic system has become the most sought after in the recent times. These are electronics items than are flexible in nature that can be rolled, twisted, bent etc. with minimal or no effect on its electronics components. These electronics components can be adjusted according to the requirement. Convention Complementary Metal Oxide Semiconductor or CMOS have hard and stiff integration made up of tough silicon based chips which are difficult to bend and adjust it according to our requirements[1] . And thus, this gives rise to the concept of flexible electronics. Thin Film Transistors (TFTs) forms the basis of these kind of electronic circuits. These flexible electronics are made on various substrates including thin glass film also known as glass foil, metal foil, polymeric substrates, organic substrates and so on. Out of these organic and polymeric film are the most preferred because of their naturally in-built flexibility possessed by these substances.

Organic and Polymeric films have very low process temperatures, close to room temperatures and as a result of this electronic circuits can be easily fabricated on these films.[2] This fact proves to be an advantage. Lower process temperatures is associated with lower cost of production. The cost of production hugely depends on the process temperature of the substrate[19]. Higher the process temperature higher is the investment. The cost of the substrate also increases, which can withstand the high temperature it has to be processed. Also the throughput decreases because of the time required the elevate the temperatures to the required level.

Thus, we can see that the lower process temperatures of Organic TFTs works to their advantage. For the manufacture if processes like additive printing is used the cost of the expensive components and the expensive process of photolithography can be reduced or eliminated entirely, thus further reducing the cost of production [11].

Organic Light Emitting diodes (OLEDs), Organic Field Effect transistors(OFETs), Organic photovoltaics are few of the many examples of organic flexible electronics[5].

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Active Matrix Displays are the most compelling result of Organic Thin Flim Transistors on flexible substrates. Along with this Active matrix liquid crystal displays (AMLCDs), active matrix electrophoretic displays, and active matrix organic light-emitting diode (AMOLED) displays, radio frequency identification (RFID) tags are also a result of OTFTs

However, one of the major issues concerning the organic flexible electronics is the compromise that has to be made between the device performance and the flexibility [11]. Numerous processes have been developed to produce high performance organic flexible electronic components. Few of the processes are

1.1 Intrinsically Flexible Organic Components

The naturally low modulus of elasticity of components like semiconductors, insulators substrates, electrodes etc, and especially the low value of the Young's Modulus makes them highly bendable and hence preferable for flexible electronics.[2]. Development of polymeric and small molecule based semiconductor has given a way for the manufacture of various active layers for many different kinds of organic flexible electronic [3].

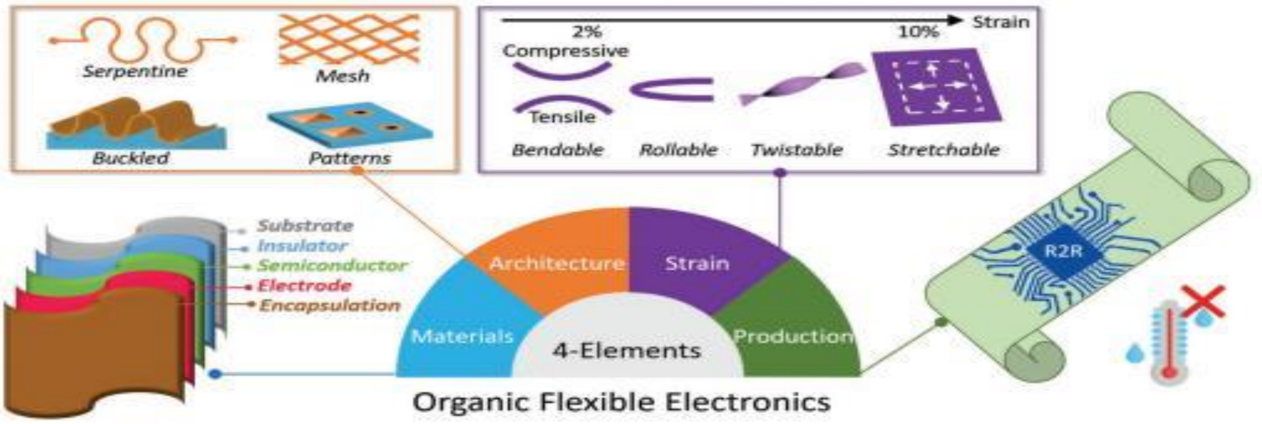

Fig.1. Important components for the development and fabrication of organic flexible electronics [11]

1.2 Fundamental Mechanical Deformability

The internal electrical stability of organic flexible electronics is affected by any kind of external mechanical impetus. The deformation caused by these any kind of mechanical stimulus is tested under both static and dynamic conditions. Rolling, bending twisting etc. fall under the static methods. Continuous cycle of mechanical stimulation falls under the category of dynamic methods[18].

1.3 Continuous Processing Techniques

One of the key issues in improving the fabrication and production of organic flexible electronics is a continuous processing technology. Presently small area devices are using the spin casting technique to deposit a thin film on them. Coating and printing are two steps solution to this problem. Both of these approaches are compatible with roll to roll processing and give a good throughput for low temperature and large volume organic flexible electronics [6].

1.4 Structural Engineering

To increase the resistance of the organic flexible circuit from deformation, this method of structural engineering is used. The capacity to endure the deformation is increased by the introduction of interconnects of flexible nature[4].These interconnects can take various shapes like that of a snake or an arc. Elastomers pre-strained in various patterns like waves or square shaped are also used to increase the deformation tolerance. This engineering method is used for adding some degree of stretchability to those flexible components which lack this stretchability [5] .

2 Parameters for Fabrication of OTFT

Organic Thin Film Transistors forms the basis for Organic electronics built on flexible substrates. But while building these certain parameters need to be kept in mind. These parameters govern and shape the functionality of the complete flexible electronic circuit.

2.1 Field Effect Mobility

The drain current in a n-channel metal oxide field effect transistor is given by the following equation:-

$$I_D=\frac{W}{L}\mu_{FE}C_{ox}\,[(V_{GS} - V_t)\,V_{DS} - V^2_{DS}/2] \quad \ldots(1)$$

Where,
μ = Field effect mobility
W= Width of channel
L= Length of channel
V_{GS} = Gate voltage
V_t = Threshold Voltage
V_{DS} = Drain to source voltage.

Experimentally it has been found that the value of mobility μ is determined by the values of V_{GS} ,V_{DS} which makes it somewhat similar to small signal gain of an amplifier or can be also called a small signal bias dependent quantity.

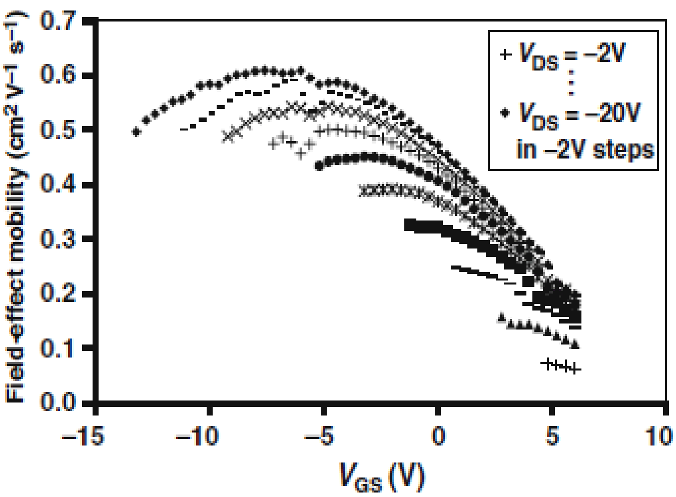

Fig.2. *Effect on mobility due to dependence on gate voltage for a pentacene OTFT with SiO2 gate dielectric [7].*
From the graph it can be seen that mobility reduces at higher gate voltages.

2.2 Threshold Voltage

OTFT usually have very high and uncontrollable values of threshold voltages. Their values may reach tens of volts. Low values of threshold voltage are desirable for applying in electronic circuits. This helps in keeping the power consumption by the circuit low.

The magnitude of the threshold voltage can be reduced and brought under control by using monolayers which are self assembled, gate dielectric before semiconductor deposition. Another method can be by keeping the capacitance high at the gate dielectric. However the yield through this process is often low and the results in high leakage at the gate terminal.

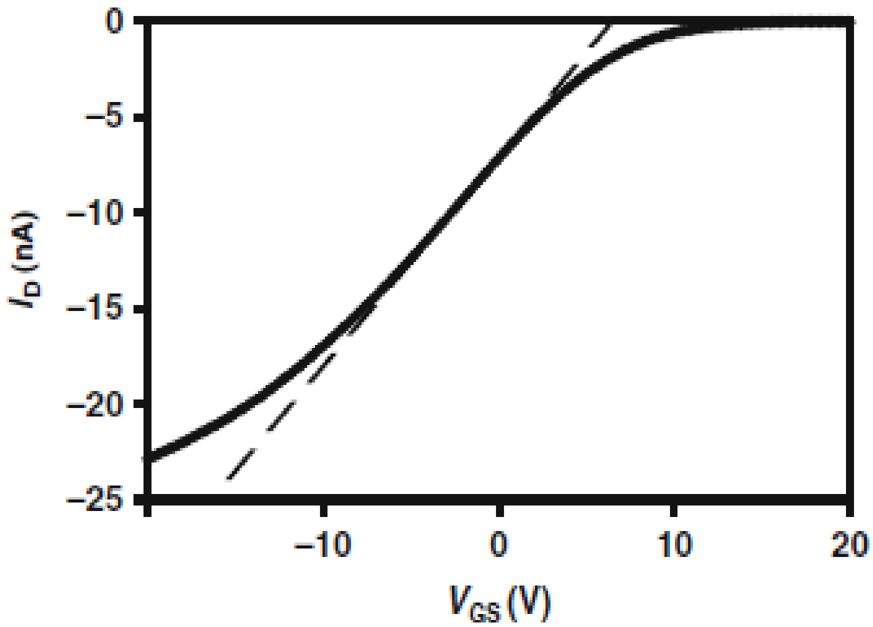

Fig.3. *Drain current measured at different values of gate to source voltage at the linear region in the linear region of operation of a pentacene OTFT with SiO2 gate dielectric. The dashed line is the tangent to the curve giving the maximum value [7].*

2.3 Subthreshold Swing

The drain current in a MOSFET in the Subthreshold region is given by the following equation

$$I_D = \frac{W}{L} K \mu_{FE} C_{ox}(1 - e^{-qV_{DS}/kT})\, e^{qV_{GS}/n\,kT} \quad ..(2)$$

Where,

K= the constant determined by the material of the device.

n= Ideality factor

T= Absolute temperature

The subthreshold swing 'S' can be given by the reciprocal value of subthreshold slope which is aptly defines the subthreshold behaviour.

So, According to the definition

Subthreshold Slope= $\partial \log ID/\partial VGS$

Then,

Subthreshold swing = $[\partial \log ID/\partial VGS]^{-1}$

The inverse of subthreshold slope.

The subthreshold swing indicate the change required in gate voltage to bring about a change of one decade to the output or drain current and hence the unit of subthreshold swing is given by voltage/decade.

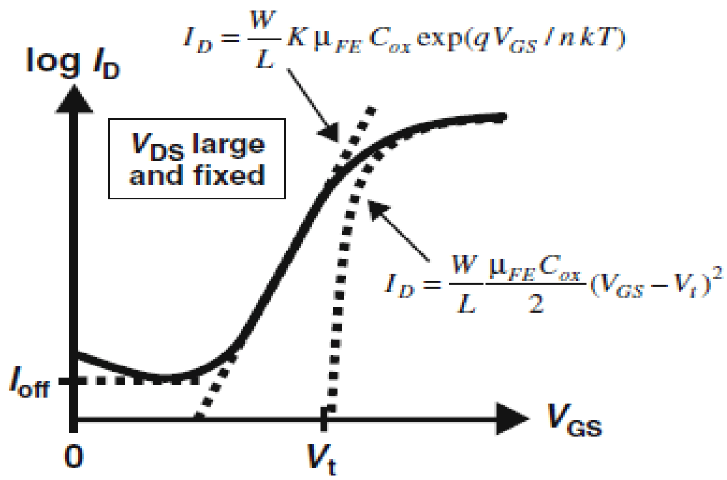

Fig.4. *The graph illustrates the variation in the value of subthreshold swing in the subthreshold region. When equation (2) is on a logarithmic swing a straight line yields as shown in the graph [7]. A low value of Subthreshold swing is usually preferable for electronics devices. The typical value of subthreshold swing of an OTFT is 500 mV − 5 V/decade (OTFTs), which is usually considered high when compared to silicon devices.*

2.4 Contact Resistance

Establishing a good electrical contact between the organic semiconductor is important, which is often difficult. Due to this large resistances creeps in series with source and drain. In OTFT , gate voltages determine these contact resistance. These decrease with decrease in gate voltage just like the resistances in the channel. However channel resistance and contact resistance are very different things. The contact resistance is completely independent of the length of the channel. Contact resistances usually impact the output characteristics of an OTFT. It usually results in a "hooked" shaped curve.

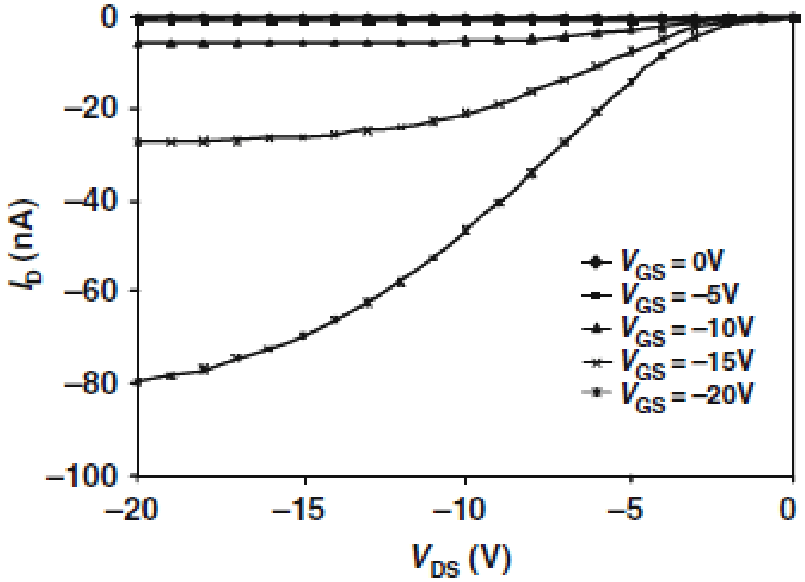

Fig.5. *The graph shows the "hooked" shaped output characteristic of a pentacene OTFT [7].*

2.5 Bias Stress Instability and Hysteresis

Bias stress instability and hysteresis are the phenomena which are dependent on the memory element of the system. The voltage applied to the device in the past affects the DC characteristic of it. Although there are methods that can increase the tolerance these memory effects, but still these kinds of effects are not desirable in electronic systems

Bias stress instability is a long term change. A positive gate bias shifts the threshold voltage to more positive voltage side and a negative one to the negative side. While, the hysteresis is a short term change which is reversible in nature It creates loops in the characteristic curve, depending on the direction in which bias voltages are shifted.

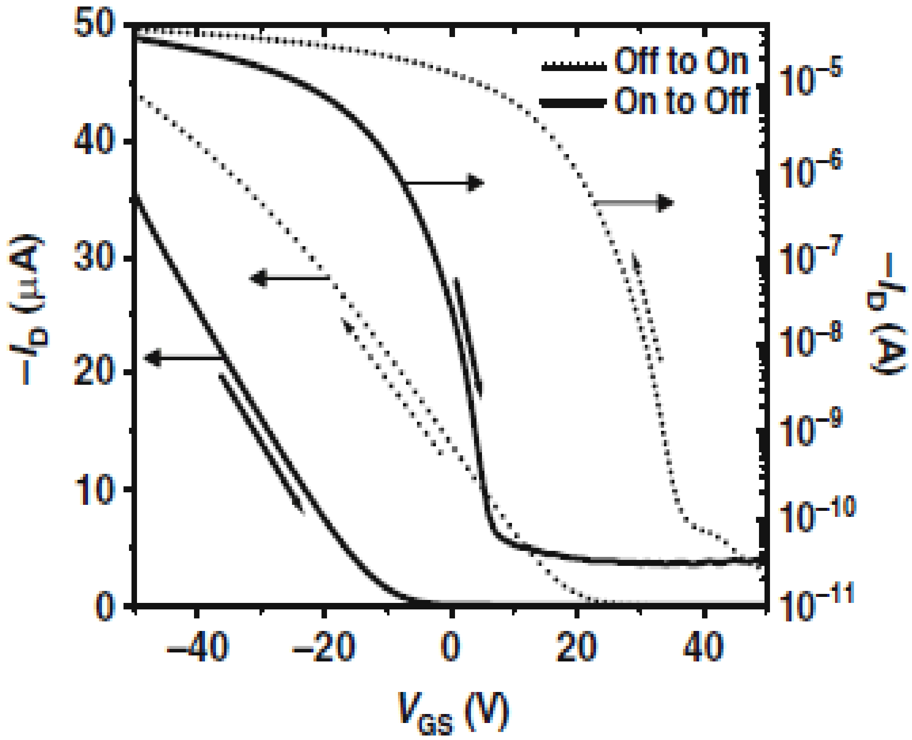

Fig.6. *Hysteresis cause loops in the transfer characteristic of a pentacene OTFT in the liner region [7].*

3 Applications of Flexible Electronics

OTFT are the the backbone of many organic electronics and consequently for various organic flexible electronics. OTFT consists of source, drain and gate like any other three terminal device. The gate voltage (V_{DS}) controlling the amount of current flowing in the circuit. OTFT can be directly fabricated onto flexible substrates with large areas and at low processing temperatures. Different kind of flexible sensors make use of OTFT.

3.1 Sensors

OTFTs give shape to this exciting concept of flexible sensors which can be worn by humans and can be used to monitor real time bodily functions. Being flexible it can be usually sown to a piece of clothing worn by human. Integrating OTFTs with these sensors brings in its quality of processing signal, amplification, signal transduction and the reduction in size that can be brought about by its use. Biosensors Photosensors, Stress sensors and many other kinds of sensors have made use OTFTs.

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Organic Field effect transistors (OFETs) a kind of (OTFT) is used to sense DNA under arid conditions [8]. Another kind of biosensors is organic electrochemical transistor (OECT), which has high sensitivity can can be used as sensors for both chemical and biological applications

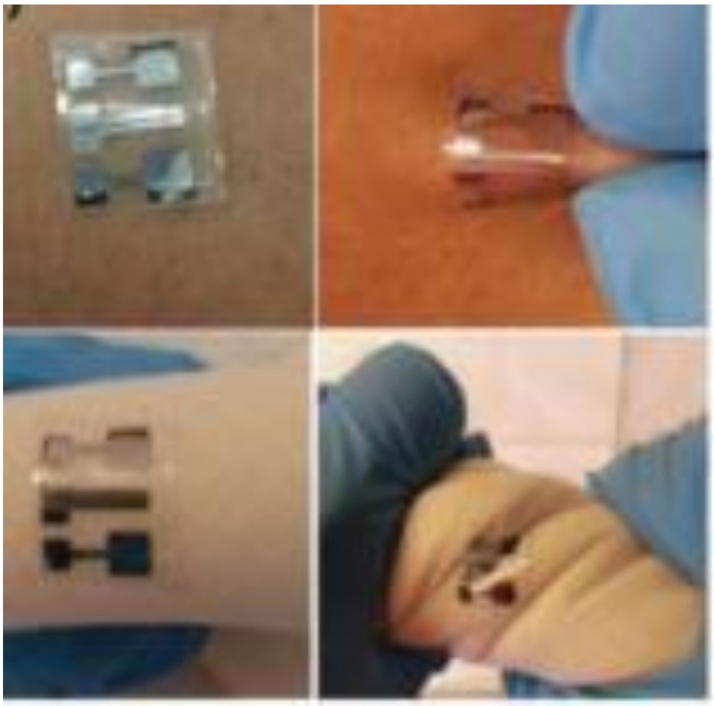

Fig.7. *Shows the OECT in different surfaces [11].*

We also have organic phototransistor (OPT) which have a CMOS like configuration and are highly sensitive to light signals [9]. These can change the density of charge carriers in the OTFT, which in turn affects the conductance of the channel [10].

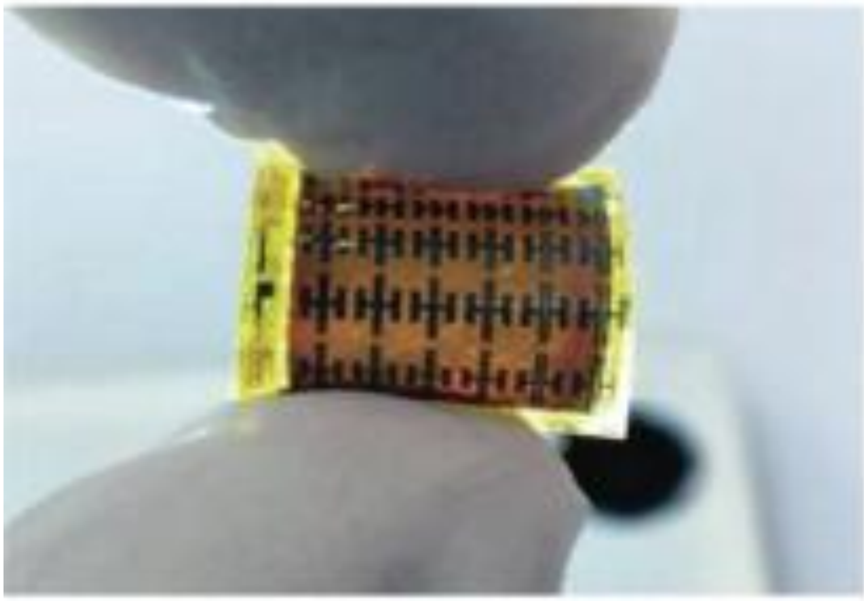

Fig.8.*Photograph of the flexible $CH_3NH_3PbI_{3-x}Cl_x$/PEDOT:PSS phototransistor [11].*

3.2 Active Matrix Display

Digital watches, Seven segment displays and devices like these have displays having low resolution. Each element in these devices have an external connection. This kind of an approach is futile where higher degree of resolution is required because many external connections required to achieve this improvised resolution. For this reason the matrix arrangement is adopted in which the arrangements of the pixel is in the form of rows and columns just like that in a matrix [12]. This matrix arrangement is divided into active and passive matrix display. Active matrix display is costlier than the passive one because it contains one or more than one element for switching for each pixel. The substrate containing these switching element of a device is called the backplane [13].

Because of the numerous drawbacks of passive matrix display, active matrix display is taken into use despite the heavy cost of production.

OTFT are used in the backplane of many flat panel displays . To name a few of them AMLCDs, AMOLED and electrophoretic displays [14].

Fig.9. *Shown above is an electrophoretic display. First of its kind, an OTFT display using pentacene TFT [15]*

3.3 Flexible Organic Circuit

OTFTs are used in various other devices and circuits to build different kinds of flexible electronics . Flexible integrated circuits, like microprocessors, amplifiers, use OTFTs. Manufacturing cost of RFID tags and flexible displays are reduced when OTFTs are used in the processing [16]. Thus there are arrays of application of OTFTs in flexible electronics.

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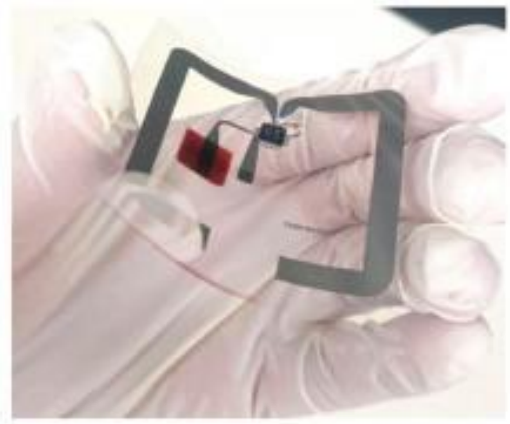

Fig.10. *All printed RFID tag of 1 bit using roll to roll technique [17].*

4 Conclusion

The use of organic thin film transistors on flexible substrates can give rise to exciting new fields of electronics. These are used in matrix display, various kinds of integrated circuits. These transistors being built on organic flexible substrates can be processed at a low temperature and has the advantage of low investment. The power consumed by them is also low. These can be integrated with wreable fabric which can be efficiently used for medical purposes. With low cost of production with an addition of flexibility will shoot the efficiency of these electronic circuits to a new level.

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