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OVERVIEW ON FLEXIBLE ELECTRONICS TECHNOLOGY

By

1st Sandeep Jayswal, 2nd Sourabh Kumar, 3rd Deepak Singh
1st Assistant professor ,dept.of ECE engineering,C.I.T.M. JAIPUR
2nd Student of IV year,ECE engineering,C.I.T.M. JAIPUR
3rd Student of IV year,ECE engineering,C.I.T.M. JAIPUR
1st Jays.Sandeep69@gmail.com, 2nd iamskyuvraj@gmail.com

ABSTRACT
Flexible electronics is a new trend in electronics industry to handle the increasing burden on chips. It is a technology for assembling electronic circuits by mounting electronic devices on flexible thin plastic substrate. This technology is having many benefits or Advantages like their light weight, favorable dielectric properties, robust, high circuit density and conformable nature. Devices and circuits can be rolled away when not required. These types of devices offer properties like clarity, dimensional stability, low coefficient of thermal expansion, elasticity etc. Recent advances in organic and inorganic based electronics proceeds on flexible substrate, offer substantial rewards in terms of being able to develop displays that are thinner, lighter and can be rolled or folded when not in use. This paper will discuss about the properties, preparation methods, applications and challenges in this rapidly growing industry.

Keywords :
Electronics, Flexible, Circuits, Silicon, Foldable.

1. Flexible Electronics
Introduction

Fig. 1 Illusion of flexible display(Source: Openpr)

Flexible electronics, also known as flex circuits, is a technology for assembling electronic circuits by mounting electronic devices on flexible plastic substrates, such as polyimide, PEEK or transparent conductive polyester film. Additionally, flex circuits can be screen printed silver circuits on polyester. Flexible electronic assemblies may be manufactured using identical components used for rigid printed circuit boards, allowing the board to conform to a desired shape, or to flex during its use. An alternative approach to flexible electronics suggests various etching techniques to thin down the traditional silicon substrate to few tens of micrometers to gain reasonable flexibility, referred to as flexible silicon (~ 5 mm bending radius).

Flexible electronics have recently attracted much attention since they enable many promising applications such as RFID tags, solar cells ,bio-sensors, wireless power and signal transmission sheets ,e-skin, e-paper and flexible display. The characteristic of flexible electronics is not only reduced cost and they have light weight, thinner, non-breakable & new forms to create many new applications. It is an attractive candidate for next-generation consumer electronics and they will soon be part of our daily lives. Development strategy of flexible electronics is dependent on global technology progresses and market forecasts. Currently, it has been estimated that there are about 1500 worldwide research units working on various aspects of flexible electronics. Market analysis estimates the revenue of flexible electronics can reach 30 billion USD in 2017 and over 300 billion USD in 2028.

2.Flexible circuit structure
Introduction
There are a few basic constructions of flexible circuits but there is significant variation between the different types in terms of their construction. Following is a review of the most common types of flexible circuit constructions

Types of Flex Circuits
1. Single-sided flex circuits
2. Double access or back bared flex circuits
3. Sculptured flex circuits
4. Double-sided flex circuits
5. Multilayer flex circuits
6. Rigid-flex circuits
7. Polymer thick film flex circuits

3.Manufacturing

Flexible printed circuits (FPC) are made with a photolithographic technology. An alternative way of making flexible foil circuits or flexible flat cables (FFCs) is laminating very thin (0.07 mm) copper strips in between two layers of PET. These PET layers, typically 0.05 mm thick, are coated with an adhesive which is thermosetting, and will be activated during the lamination process. FPCs and FFCs have several advantages in many applications: Flex circuits are often used as connectors in various applications where flexibility, space savings, or production constraints limit the serviceability of rigid circuit boards or hand wiring. A common application of flex circuits is in computer keyboards; most keyboards use flex circuits for the switch matrix.

- Tightly assembled electronic packages, where electrical connections are required in 3 axes, such as cameras (static application).
- Electrical connections where the assembly is required to flex during its normal use, such as folding cell phones (dynamic application).
- Electrical connections between sub-assemblies to replace wire harnesses, which are heavier and bulkier, such as in cars, rockets and satellites.
- Electrical connections where board thickness or space constraints are driving factors.

Advantage and Disadvantage of FPSs

- **Advantage of FPCs**
  - Potential to replace multiple rigid boards and/or connectors
  - Single-Sided circuits are ideal for dynamic or high-flex applications
  - Stacked FPCs in various configurations
- **Disadvantages of FPCs**
  - Cost increase over rigid PCBs, Repair and rework is difficult or impossible
  - Increased risk of damage during handling or use
  - More difficult assembly process

4.Manufacturing Techniques

Introduction

Polydimethylsilioxane (PDMS) is ideal substrate and composite matrix material for flexible electronics. It is optically transparent, viscoelastic, chemically and thermally stable, highly flexible ,hydrophobic and can easily be moulded with high resolution and aspect ratio. To avoid metallization Electrically Conductive Adhesive (ECA)are used. ECAs are conductive composites composed of metallic fillers within a polymeric matrix. This technology is coined as PDMS-in-PDMS electronics. Basically, flexible electronics deals with circuits developed using Thin Film Transistors (TFT). Different TFT technologies are available today to develop circuits.

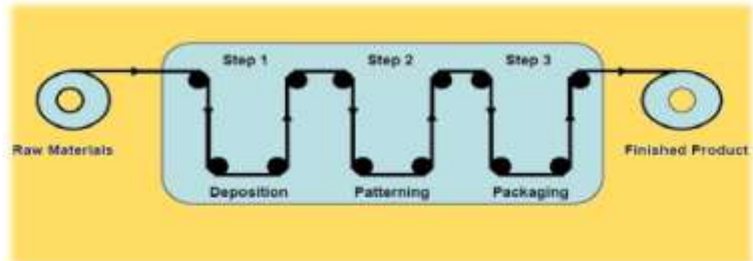

Fig 2 Row to Row Process (Source:Slideshare/fe)

5.Types of Manufacturing Technology

1. **Amorphous Silicon Technology:** Hydrogenated amorphous silicon(a Si:H)TFTs are the workforce of today's active matrix LCD displays [2-4]. The main driving force for OLED display is its emissive characteristics, good color saturation and clarity. It is also sunlight readable. This technology is suitable for the bi-stable displays such as electrophoretic and cholesteric displays, a Si:H TFT based integrated drivers can be used in application which require only occasional image updates such as advertising, map applications, point of sale labels etc.
2. **Polysilicon Technology:** Polysilicon TFTs are processed at higher temperature using laser re-crystallisation of a Si:H material and can have mobilities greater than 100cm2v-1s-1. The threshold voltages of these of TFTs are very stable. Poly-Si TFTs can be used to develop display backplanes as well as CMOS digital circuits [5]. However, the process and substrate costs are comparatively higher and thus restrict the use of these TFTs in high resolution displays in smart phones and high end radio frequency tags.
3. **Organic Thin Film Transistors**:Organic TFTs can be manufactured using a number of organic semiconductors such as Pentacene, TIPS Pentacene etc. These semiconductors can be processed at low temperatures using solution processes or vacuum evaporated processes such as spin coating and ink-jet printing [6]. Roll-to-Roll processing may bring down the cost of production. The OTFT is sensitive to air and hence its performance degrades over time when exposed to the environment .Barrier coating is required to protect it from exposure.
4. **Single Crystal Silicon on Flexible Substrates:** It is possible to develop single crystal silicon circuits on flexible substrates with mobilities greater than 500cm2v-1 s-1 and response frequencies greater than 500MHz.In this techniques, a semiconducting micro/nanomaterial known as microstructural silicon is printed using dry transfer or solution based techniques onto plastic substrates to produce high performance TFTs.
5. **Mixed Oxide Thin Film Transistors:** Mixed oxide thin film transistors such as IZO,IGZO provide better mobility, higher current densities and better stability compared to a Si:H TFTs. Another feature of mixed oxide TFT is that they are transparent. Hence, there is much interest to develop transparent electronics on large area flexible substrate.

6. **Hybrid (CMOS) Technology:** CMOS technology has several advantages over nMOS or pMOS only technologies. Speed of CMOS technology is considerably faster than any other technology with much lesser power loss. By including n-type and p-type TFTs on the same substrate, it is possible to implement CMOS circuits which reduce power consumption, leakage currents and improve the gain of the digital logic circuits. Research done at Flexible Display Centre in collaboration with University of Texas at Dallas shows that these CMOS logic circuits are more stable compared to a Si:H TFT circuits. This is because the V(t) of the a Si:H TFT shifts in positive direction with electrical stress while that of organic TFTs shift negative as shown in fig. 1. In this technology, a Si-H TFTs and Pentacene TETs on PEN substrate and successfully demonstrated a CMOS column driver for electrophoretic displays.

6. Flexible circuit materials

Introduction

Each element of the flex circuit construction must be able to consistently meet the demands placed upon it for the life of the product. In addition, the material must work reliably in concert with the other elements of the flexible circuit construction to assure ease of manufacture and reliability. Following are brief descriptions of the basic elements of flex circuit construction and their functions.

1. **Base material:** The base material is the flexible polymer film which provides the foundation for the laminate. Under normal circumstances, the flex circuit base material provides most primary physical and electrical properties of the flexible circuit. In the case of adhesiveless circuit constructions, the base material provides all of the characteristic properties. While a wide range of thickness is possible, most flexible films are provided in a narrow range of relatively thin dimension from 12 µm to 125 µm (1/2 mil to 5 mils) but thinner and thicker material are possible. Thinner materials are of course more flexible and for most material, stiffness increase is proportional to the cube of thickness.
2. **Bonding adhesive:** Adhesives are used as the bonding medium for creating a laminate. When it comes to temperature resistance, the adhesive is typically the performance limiting element of a laminate especially when polyimide is the base material. Because of the earlier difficulties associated with polyimide adhesives, many polyimide flex circuits presently employ adhesive systems of different polymer families. However some newer thermoplastic polyimide adhesives are making important in-roads. As with the base films, adhesives come in different thickness. Thickness selection is typically a function of the application. For example, different adhesive thickness is commonly used in the creation of cover layers in order to meet the fill demands of different copper foil thickness which may be encountered.
3. **Metal foil:** A metal foil is most commonly used as the conductive element of a flexible laminate. The metal foil is the material from which the circuit paths are normally etched. A wide variety of metal foils of varying thickness are available from which to choose and create a flex circuit, however copper foils, serve the vast majority of all flexible circuit applications. Copper's excellent balance of cost and physical and electrical performance attributes make it an excellent choice.

7. Flexible Electronic Components

Introduction

Fast flexible electronics operating at radio frequencies (>1 GHz) are more attractive than traditional flexible electronics because of their versatile capabilities, dramatic power savings when operating at reduced speed and broader spectrum of applications. Transferrable single-crystalline Si nanomembranes (SiNMs) are preferred to other materials for flexible electronics owing to their unique advantages. Further improvement of Si-based device speed implies significant technical and economic advantages. While the mobility of bulk Si can be enhanced using strain techniques, implementing these techniques into transferrable single-crystalline SiNMs has been challenging and not demonstrated.

- **Resistors and Capacitors**

The past approach presents severe challenges to achieve effective doping and desired material topology. Here we demonstrate the doping techniques with self-sustained strain sharing by applying a strain-sharing scheme between Si and SiGe multiple epitaxial layers, to create strained print-transferrable SiNMs. We demonstrate a new speed record of Si-based flexible electronics without using aggressively scaled critical device

dimensions.

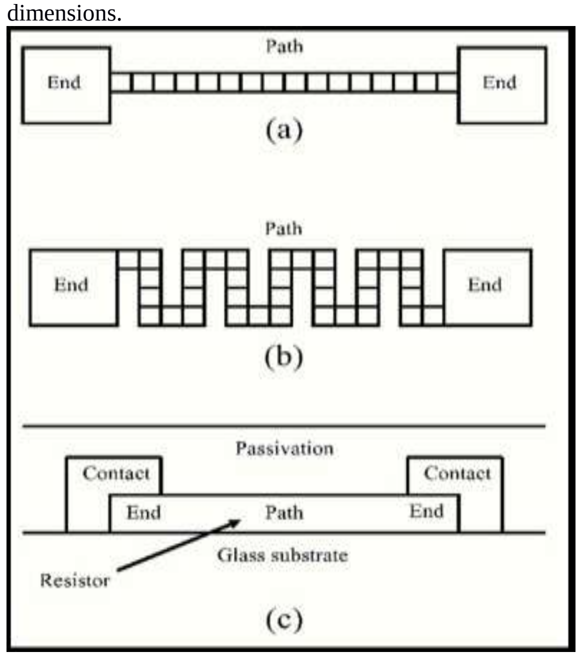

Fig. 3 Structure of resistor(Source:extra.ivf)

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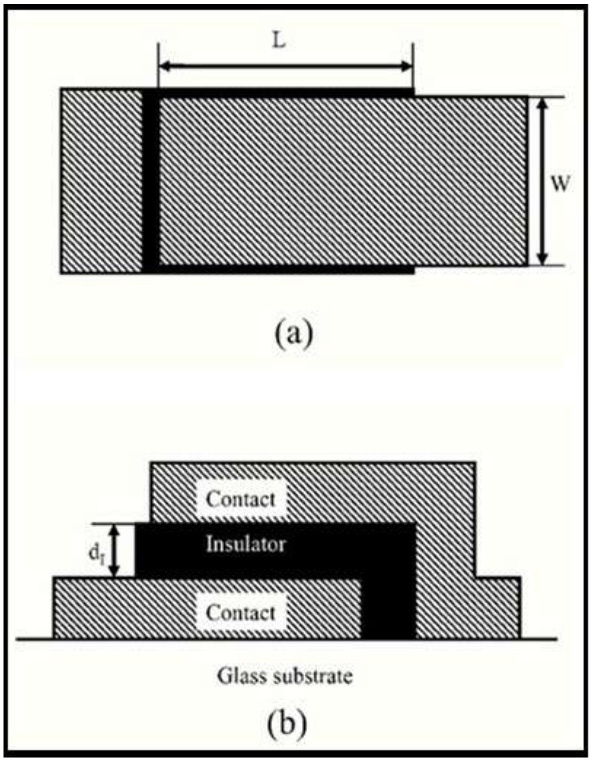

Fig. 4 Structure of capacitor(Source:mdpi.com)

The given figure above shows the structures of thin film resistors and capacitors which are constructed on flexible substrate and the conductive paths are made up of flexible materials such as silicon nanomembranes, grapheme, carbon nanotubes etc. Nanotechnology is to a large extent for the manufacturing of electronic components

- **Memory, Amplifiers and Ring Oscillators**

At the International Electron Devices Meeting (IEDM) last fall IBM researchers demonstrated CMOS circuits —including SRAM memory and ring oscillators—on a flexible plastic substrateThe extremely thin silicon on insulator devices had a body thickness of just 60 angstroms. IBM built them on silicon and then used a room-temperature process called controlled spalling, which essentially flakes off the Si substrate. Then they transferred them to flexible plastic tape. The devices had gate lengths of <30 nm and gate pitch of 100 nm. The ring oscillators had a stage delay of just 16 ps at 0.9 V, believed to be the best reported performance for a flexible circuit.

In a recent edition of the journal Nature Communications a team of researchers from the University of Pennsylvania showed that nanoscale particles, or nanocrystals, of the semiconductor cadmium selenide can be "printed" or "coated" on flexible plastics to form high-performance electronics. Because the nanocrystals are dispersed in an ink-like liquid, multiple types of deposition techniques can be used to make circuits, wrote the researchers. In their study, the researchers used spin coating, where centrifugal force pulls a thin layer of the solution over a surface, but the nanocrystals could be applied through dipping, spraying or ink-jet printing as well, they report.

Using this process, the researchers built three kinds of circuits to test the nanocrystal's performance for circuit applications: an inverter, an amplifier and a ring oscillator. All of these circuits were reported to operate with a couple of volts, according to the researchers an important point since If you want electronics for portable devices that are going to work with batteries, they have to operate at low voltage or they won't be useful.

- **Batteries**

One of the things seemingly hampering advances in bendable electronics research is uncertainty surrounding a product's power source. At the University of Delaware, Bingqung Wei and his colleagues are researching energy sources that are scalable and stretchable. In a report published in Nano Letters, a journal of the American Chemical Society, Wei's research team reported significant progress in developing scalable, stretchable power sources using carbon nanotube macrofilms, polyurethane membranes and organic electrolytes. According to Wei, the super capacitor developed in his lab achieved excellent stability in testing and the results will provide important guidelines for future design and testing of this leading-edge energy storage device.

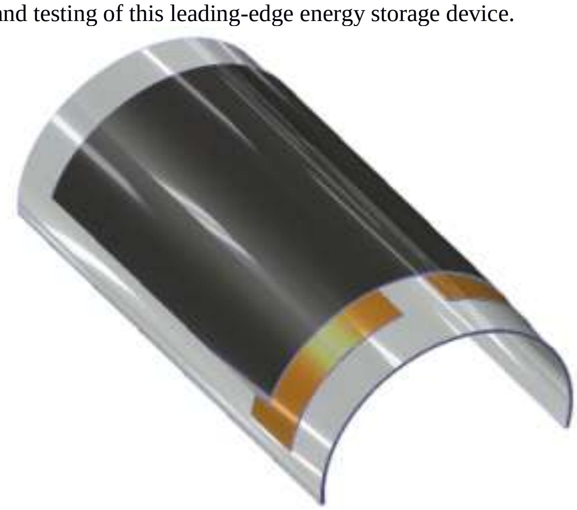

Fig 5. Flexible lithium ion battery(Source:revoseek.com)

Also in Nano Letters researchers from the Korea Advanced Institute of Science and Technology (KAIST) in Daejeon, South Korea published a study on a new bendable Li-ion battery for fully flexible electronic systems.

Although the rechargeable lithium-ion battery has been regarded as a strong candidate for a high-performance flexible energy source, compliant electrodes for bendable batteries are restricted to only a few materials, and their performance has not been sufficient for them to be applied to flexible consumer electronics including rollable displays.

The researchers presented a flexible thin-film lithium ion battery that enables the realization of diverse flexible batteries regardless of electrode chemistry. The result is a flexible Li-ion battery that can be made with almost any electrode material. Here, the researchers used lithium cobalt oxide as the cathode material, which is currently the most widely used cathode in non-flexible Li-ion batteries due to its high performance. For the anode, they used traditional lithium.

8.Applications of Flexible Electronics

A large number of applications have been developed including displays, computational systems, in energy storage and generation, health care, e-textiles etc.

- **Wireless Networking**

Stretchable antennas have been fabricated using PDMS, which is usually cast on a photo-resist mould with the desired design. The PDMS structure is then peeled away and holes introduced for injection of a liquid eutectic (Galinston:68.5%Ga,21.5%In, 10%Sn),to form the radiating elements. Another recently explored route for fabrication of stretchable PIFA antennas uses direct deposition of thin-film gold onto elastomeric substrate.

- **Healthcare**

Flexibility in electronic materials is very attractive for medical and bioengineering. Some electronics have been integrated into human bodies . For example ,bionic eye, bionic ear, optic nerve etc .heat, humidity ,salt or pressure sensor arrays can be used as bed sheet and monitor a patient in real time. Flexible thin films could also play a key role in deciphering the thought processes occurring in the brains.

- **Automotive Industry**

Intelligent roads will be engineered with the aim of improving road safety, lowering road congestion and energy consumption. The road and vehicle will also be able to interact dynamically, adjust either party to energetically optimize their systems.

- **Smart Textiles**

Recently, there is increase interest in smart textiles for health monitoring, entertainment and display applications. These smart textiles can be embedded with multiple sensors and display devices for monitoring stress, toxic gases in environment. Each smart thread is basically a shift register with a small display pixel and possibly a sensor ,which can be used to transfer data from one end to other.

- **Displays and Human-Machine Interactivity**

As a user slide fingers on the surface, the applied time varying potential includes intermittent attractive and repulsive electrostatic forces between the buried conducting layer and the finger. This electrostatic attraction varies the normal contact forces between the user's skin and surface and in turn, modulates the dynamic friction and touch perception.

- **Electronic Paper**

Currently, the most successful technology and industry is electronic paper, the main applications are e-Readers, electronic shelf labels, smart cards, electronic posters and so on . Currently, the e-Reader is not really flexible because it use a glass backplane. E-Ink Holdings and ITRI includes organic conductor and printing process, substrate is PET films which only can be processed at low temperature. ITRI also develops a passive technology of cholesterol liquid crystal which can be manufactured using a fully roll-to-roll technology.

9.Advantage and Disadvantage of Flexible Electronics

- **ADVANTAGES**
  - light weight
  - Smaller dimensions required
  - Space saving
  - Foldable and bendable
  - Increased circuitry density
  - Wide Viewing Angle
- **DISADVANTAGES**
  - Initial investment may be expensive
  - Integration of components would be challenge for engineers
  - Precision machines required
  - Lifetime
  - Manufacturing

10.Challenges

There are some challenges that still need improvement.

- Electrical Instability Reliability is critical for flexible circuit design to ensure that the circuit would operate reliably throughout its lifetime. Thin film transistor(TFTs)often suffers from electrical instability, but threshold voltage shift of a single TFT can be modelled by analyzing its operating conditions and circuit lifetime can be predicted accordingly using SPICE simulation.
- Printing Quality The printing qualities are not easy to control due to liquid off-set or jetting operations, special multilayer or large area film printing.
- Flexibility Operation The most practiced flexible operations like bending, folding or rolling is not easy guarantee due to multilayer structure. Research is going on to provide more reliable flexibility to the circuits.
- Flexible Substrate Handling and Alignment The dimensional control of plastic substrate is very difficult due to temperature, humidity and tension variation, special roll-to roll operation.
- Flexible Conductor Conductivity and Work Function The operation for flexibility and conductivity are the trade-off parameters and work function always needs to modify.

11.Future Aspects

Development strategy of flexible electronics is dependent on global technology progresses and market forecasts. The research and development is focused on big markets. Flexible electronics covers a wide spectrum of applications including flexible display, flexible solar cell, printed RFID, flexible lighting and others. Currently, it has been estimated that there are about 1500 worldwide research units working on various aspects of flexible electronics. Market analysis estimates the revenue of flexible electronics can reach 30 billion USD in 2017 and over 300 USD in 2028 [19]. Region wise, the research activities in Europe cover a wide range of topic-from materials, process, to system and applications. In the US, research is primarily driven by military applications. Asian companies invest heavily in flexible display. Today, flexible circuits which are also known around the world as flexible printed wiring, flex print, flexi circuits are used many products. Large credits goes to the efforts of Japanese electronics packaging engineers who have found a countless new ways to employ a flexible circuit technology [20]. For the last decade, flexible circuits have remained one of the fastest growing of all interconnection product market segments. A more recent variation on flexible circuit technology is one called flexible electronics which commonly involve the integration of both active and passive functions in the processing.

12.Conclusion

In this report, we have discussed some of the fabrication techniques, applications, challenges and future socioeconomic trends of thin –film technology are likely to enhance the performance of the devices. Although this field is growing and getting matured, it has been expanding rapidly and dynamically. The keys to success include grasping the tempo, building up a complete value chain ,and attracting the necessary entities to join the efforts and cooperate. This paper gives a brief overview of how the field of flexible electronics has evolved over the years and what the future holds for the large area, rugged, low power electronics. Some of the applications which can be developed on flexible substrates have been introduced.

13.References

1. https://scholar.google.com/scholar?hl=en&q=flexible+electronics&oq=Flexible+
2. **Flexible electronics: materials and applications:** WS Wong, A Salleo - 2009
3. **Overview of flexible electronics technology:** IC Cheng, S Wagner - **Flexible Electronics**, 2009
4. J.-M. Liu, T.M. Lee, C.-H. Wen, C.-M. Leu,"High Performance organic-inorganic hybrid plastic substrate for flexible displays and electronics", J.Soc.Inf.Display, Vol. 19, No. 1, pp. 63-69, 2011.
5. P.G'orrn, M.Sander, J.Meyer, M.Kroger, E.Becker, H.H. Johannes, W.K.T. Riedl,"Towards see through displays:fully transparent thin film transistors driving transparent organic light emitting diodes", Adt. Motor., Vol. 18, pp. 738-41, 2006.
6. Chin-Chin Tsai,"Recent Development in Flexible Electronics", The 16th Opto-Electronics And Communications Conference, OECC, 2011.
7. T.Ryhanen,"Nanotechnologies for future Mobile Devices", Cambridge, U.K.: Cambridge Univ. Press, 2010.
8. W.Xiong, U.Zschieschang, H.Klauk, B.Murmann,"A 3V, 6b Successive Approximation ADC using Complementary Organic Thin-Film Transistors on Glass", to appear, ISSCC Dig.Techn. Papers, Feb. 2010.
9. Manuel Quevedo, S.Gowrisanker, H.N.Alshareef, B.E. Gande, D.Allee, S. Venugopal, R.Krishna, K.Kaftanoglu, "Novel materials and integration schemes for CMOS –based circuits for flexible electronics", Meet. Abstr.-Electrochem. Soc.902, 2408, 2009.
10. W.Xiong, U.Zschieschang, H.Klauk, B.Murmann,"A 3V, 6b Successive Approximation ADC using Complementary Organic Thin-Film Transistors on Glass", to appear, ISSCC Dig.Techn. Papers, Feb. 2010.
11. D.Purves, Neuroscience, Sunderland, MA: Sinauer, 2008.
12. IPENZ Conference, Institution of Professional Engineers New Zealand, and CSP Pacific (Firm)Engineering, Providing the Foundations for Society,Wellington, New Zealand ,papers presented in the Technical Programme, Feb. 9-13, 1996.
13. J.-M. Liu, T.M. Lee, C.-H. Wen, C.-M. Leu,"High Performance organic-inorganic hybrid plastic substrate for flexible displays and electronics", J.Soc.Inf.Display, Vol. 19, No. 1, pp. 63-69, 2011.
14. T.Ryhanen,"Nanotechnologies for future Mobile Devices", Cambridge, U.K.: Cambridge Univ. Press, 2010.
15. Chin-Chin Tsai,"Recent Development in Flexible Electronics", The 16th Opto-Electronics And Communications Conference, OECC, 2011.
16. http://www.ncflexe.in/