

Flexible technology for Electronics: Its Derivatives and Possibilities

Deovrat Phal¹, Akshay Narkar², Manoj Patil³

^{1,3}Department of Electronics Engineering, Shah and Anchor Kutchhi Engineering College, Chembur-400088

²Department of Mechanical Engineering, Lokmanya Tilak College of Engineering, Navi Mumbai-400709

Abstract

With the inkjet printing technology becoming more popular, integration of circuits developed on flexible substrates which are easily embedded inside the machine as against the rigid PCB circuits is becoming more prevalent. Much of the research has been done in applications of such circuits in human body implants or for other low cost applications. This paper concentrates particularly on applications of such circuits in the field of consumer electronics, disposable electronics, display technology and discusses the derivatives of this technology and its future possibilities.

Keywords– inkjet printing; paper-based substrate; printable electronics

I. INTRODUCTION

With the new demanding applications of electronics that require circuits that can be folded, easily embedded or deployed once biologically implanted or deployed in space, as required in avionics applications inkjet printing of circuits is gaining importance. The need for flexible circuits in robotics arises because of the numerous wire connections from the controller circuits on rigid PCB to the actuators on the robots.

II. FLEXIBLE ELECTRONICS

A. Substrate

The choice of substrate largely depends on the application. For electronics application starting from paper or plastic anything can be used as the substrate so that it could be folded inside the electronic device and no separate connections are needed from the controller circuits on rigid PCB to the device.

The dielectric strength of the substrate is also important, depending on the application. Generally PCBs have a ground plane on the bottom layer and top layer has signals and supply voltages. Applications requiring high voltage levels can have substrates like Polyimide which have high dielectric strength. Paper or plastic can be used for low voltage applications because of poor dielectric strength.

B. Traces material

The material used for traces is generally silver or aluminium. Gold can also be used but is rarely used except for connections requiring less resistivity.

The material used for printing and making circuit also influences the choice of substrate since the material should easily stick to the surface.

C. Interconnects material

Conductive adhesive should be used for connecting the components to the flexible substrate. It is advisable to stick the components to the substrate before soldering them for better connections.

D. Advantages

Paper, as a substrate, is recyclable and its conversion cost is comparatively less as compared to the glass epoxy or copper clad printed circuit boards. Use of such substrates helps greatly in reducing the electronic waste produced, unlike the waste produced by rigid PCB's. Foldable substrates like paper, plastic which has lesser dielectric strengths can also be used in low voltage applications. Power dissipation is comparatively less in the inkjet printed circuit as the length of the connection and hence the resistance from the power supply to the end electronic component or the IC is greatly reduced. The inkjet printed circuit can rotate without causing to restrict the motion of the actuators, hence an advantage to the robotics industry. In space laboratories we would not want a robotic arm to get stuck up because of mere wire entanglement and thus flexible circuits are an advantage. Moreover, the circuits are less bulky and hence occupy less surface area and volume. The use of silver, unlike the use of copper, is more advantageous in terms of electrical conductivity and resistivity. At 20° C, conductivity of silver is 6.3×10^7 S/m while that of copper is 5.96×10^7 S/m while at same temperatures the resistivity of silver is 1.59×10^{-8} ohm-m while that of copper is 1.68×10^{-8} ohm-m.

III. INKJET-PRINTING TECHNOLOGY

A. Patterning

The circuit can be designed in any software like Eagle or Altium and the design file can be saved as a GERBER file or a CAD or any image file with the desired resolution. The printing resolution and the resolution at which the circuit's image is generated should match.

B. Printing

The actual printing is done using Ag-aerosol or silver particles dissolved in some suitable solvent or even Aluminium can be used. Instead of the normal printing ink which is generally used in printers, Ag-ink is used. The pattern which is designed is directly printed on the desired substrate. The surface onto which the printing has to be done or in other words the circuit has to be developed, can be usually cleaned by IPA in case of plastic/Polymide substrates.

C. Components

Similar to the SMT components which are soldered to rigid PCB, surface-mount components can also be stuck to the flexible and foldable circuits with conductive adhesive. SOIC package components are the most easiest to connect to flexible substrates, as against through-hole packages or TQFP packages which are bit clumsy with regards to connections on to the flexible substrates.

IV. DERIVATIVES

A. Our experimental prototype

To begin with, we thought of designing and developing our own flexible PCB using everyday material. Plastic was the most welcomed option, being widely available and at economical rates. The IC 555 LED blinking circuit was finalized and implemented as per prior calculations, with 500ms ON time and 800msec OFF time. The circuit was successfully built and tested and gave impressive results.

A 0.3mm thick plastic sheet was used as a substrate material for the circuit. Fine grooves were marked out using a sharp plate and single strands of wires were inserted inside to complete a connection. Each strands were soldered directly to the component (the 555 IC, capacitors and resistors). Two CR2032 Lithium button cells of 3V each were connected in series to provide a bias supply of 6V to the IC 555. To provide extra strength a layer of cello tape was wrapped on either sides of the plastic PCB.

The plastic circuit was tested drastically. It was folded, kept inside pocket, tied with rubber band, crumbled with both hands, but still worked successfully.

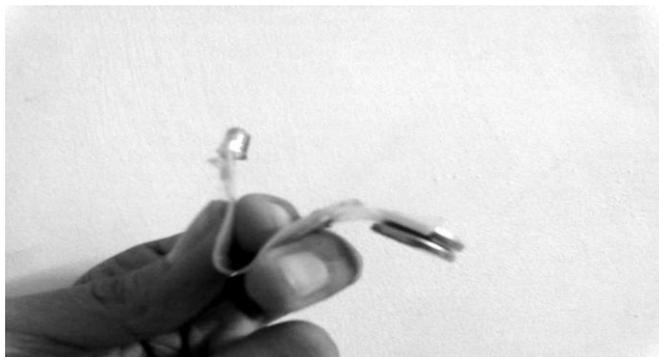


Fig.1. Our flexible PCB prototype held between fingers



Fig.2. Our flexible PCB prototype held freely

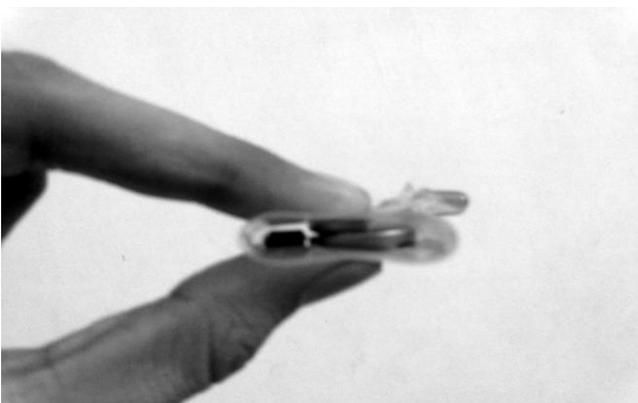


Fig.3. Our flexible PCB prototype folded completely



Fig.4. Our flexible PCB prototype in crumbled condition

B. Derivative I: Polyimide and copper

Polyimide has excellent dielectric strength, thermal stability, chemical resistance, flexibility, and dimensional stability. While Polyimide is widely used in electrical applications such as insulation for field coils, motor and generator liners, as well as wire and cable insulation, it is particularly well suited for use as a dielectric substrate for flexible copper clad laminate. In fact, flexible circuit laminate is the largest single end use for Polyimide today. Polyimide HN is the primary dielectric core for adhesive based flexible circuits. With a maximum operating temperature of 180 C, compared to 105 C for typical adhesive based laminates, many higher temperature applications became feasible. Its superior chemical resistance enabled the use of flex circuits in much harsher environments, such as that found in under-the-hood automotive applications. Probably most important, though, is the improvement in electrical properties. Adhesive based laminate systems have higher loss tangents and dielectric constants and consequently, very high signal attenuation, especially at high frequencies. Copper traces can be used with Polyimide because of the excellent adhesive properties of the Polyimide-copper material combined with superior dielectric properties of Polyimide. These trace-substrate materials are best suitable for high voltage applications in automation firms, where there may be a need for heavy actuation.

C. Derivative II: Plastic and conducting polymer

For low voltage applications where power requirements are not a concern, plastic-polymer combination can be used. Although the strength of these PCB's cannot be guaranteed, they can be printed over and over, given the low manufacturing cost of plastic.

The combination of plastic and conducting polymers silicon in contact less, readable bar code labels. The resulting IC's are lower in cost when compared with their silicon counterparts and as they still operate when the foils are sharply bent, they are ideally suited for integration into product wrappings for soft packages. Only a limited number of process steps are needed to produce these low-cost disposable electronic-identification devices. A Research by Phillips has already demonstrated the all-polymer approach by manufacturing prototypes of a complete radio frequency (RF) identification tag with programmable code generator and anti-theft sticker.

Semi-conductive polymers have been previously used as the active component in Metal-Insulator-Semi-conductor, Field Effect Transistors (MISFETs). Now days, the conductive and insulating parts of the transistor have also been made from polymers.

The substrate used in the new all-polymer process is a polyimide foil with a conducting polyaniline layer containing a photo initiator. This layer is exposed to deep-UV light to create the shaping of interconnects and electrodes. The process reduces the conducting polyaniline to non-conducting leucomeraldine. A 50mm semi-conducting layer of polythienylene-vinylene is then applied by spin coating and converted at an elevated temperature, using a catalyst. A polyvinylphenol spin coated layer is used as gate dielectric and as insulation for the second layers of interconnect. This interconnect is created in the top polyaniline layer using a second mask. Vertical interconnects (vias) needed to link transistors in logic circuits are made by punching-through overlapping contact pads in bottom and top layers using a mask as guidance. Stack integrity is assured and the process does not imply a temperature hierarchy. Logic functionality comprises a programmable code generator, which produces a data stream of 15 bits at 30 bits per second. The generator is 27 sq., 326-transistor, 300-via circuits with on-board clock. Future research is aimed at reducing cost and increasing the bit-rate by improving the charge carrier mobility of the semi-conductor and by scaling-down the lateral dimensions.

The chemical properties of conducting polymers make them very useful for use in sensors. This utilizes the ability of such materials to change their electrical properties during reaction with various redox agents (dopants) or via their instability to moisture and heat. An example of this is the development of gas sensors. It has been shown that Polypyrrole behaves as a quasi 'p' type material. Its resistance increases in the presence of a reducing gas such as ammonia and decreases in the presence of an oxidizing gas such as nitrogen dioxide. The gases cause a change in the near surface charge carrier (here electron holes) density by reacting with surface adsorbed oxygen ions. Another type of sensor developed is a "biosensor". This utilizes the ability of triiodide to oxidize polyacetylene as a means to measure glucose concentration. Glucose is oxidized with oxygen with the help of glucose oxidase. This produces hydrogen peroxide, which oxidizes iodide ions to tri-iodide ions. Hence, conductivity is proportional to the peroxide concentration, which is proportional to the glucose concentration.

D. Derivative III: Flexible LCD with grids

For low voltage applications where power requirements are not a concern, plastic-polymer combination can be used.

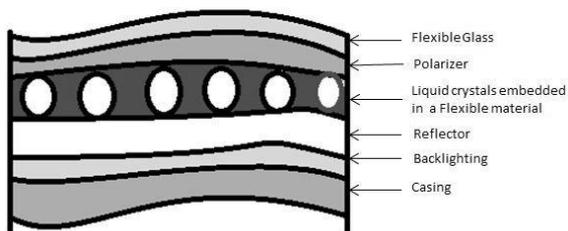


Fig.5. Conceptualised design of flexible LCD

Although the strength of these PCB's cannot be guaranteed, they can be printed over and over, given the low manufacturing cost of plastic. This concept can be implemented when the rigid materials in LCD display are replaced by synthetic plastic materials.

A polymer Light-Emitting Diode (LED) is a thin light source in which a polymer is used as the emissive material. The LED's are attractive for a host of consumer applications as they operate at a low bias voltage. They enable large area devices to be fabricated inexpensively. Products, which are currently being developed, are small emissive displays and Backlights for small Liquid-Crystal Displays (LCD's). Phillips Research, the inventor in this field had demonstrated the backlight for a mobile phone LCD as an example of one of tomorrow's devices.



FIG.6. FUTURE APPLICATIONS FOR FLEXIBLE ELECTRONICS

V. POSSIBILITIES

Once the circuits can be printed on the plastic or epoxy substrates, the idea of printing the semiconductor itself on the substrate materials cannot be left aside. With proper equipment and proper doping concentration for p-type and n-type semiconductors, elementary block of electronics like diodes and transistors can be 3D printed onto the substrate. Going a step further, even Integrated

circuits can be printed with much ease than as compared to current expensive fabrication processes.

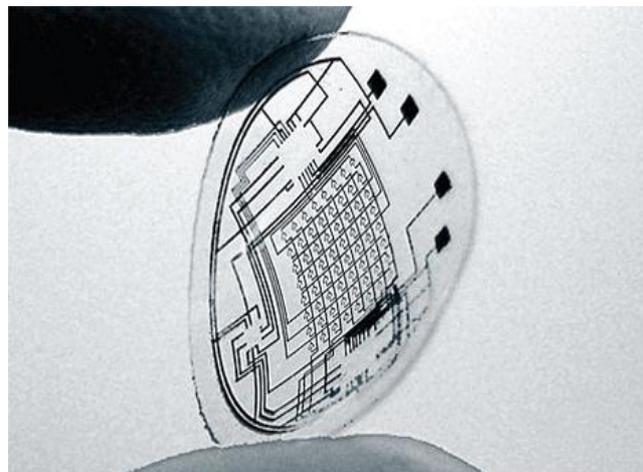


Fig.7. Future applications for flexible Electronics

As far as consumer electronics is concerned, 3D printing of semiconductor devices would result in booming market for wearable electronics. The concept of using plastic as substrate material would not only reduce the country's plastic waste, but also give less expensive consumer electronics. Be it the wearable LCD displays or the electronic contact lenses, every concept in the field of engineering, say from biomedical to mechanical can be exploited to consumer use.

With the advances in augmented reality (AR) which is bridging the distance between fiction and reality. The bionic contact eye-lenses, brain implants, cardiac implants etc. can be easily 3D printed using every day available resources with very little help from nanotech fabrication technologies.

VI. ADVANTAGES OF FLEXIBLE TECHNOLOGY

On the inkjet printed flexible PCB substrate, the Microcontroller unit, power supply unit and the control unit can be designed in one block itself. This PCB can be designed along the length of the plastic, paper or any conductive polymer and can be twisted and rotated, without causing to restrict the motion of the components.

VII. OTHER APPLICATIONS OF FLEXIBLE TECHNOLOGY

A. Biomedical - Glucose fuel cells

As implantable electronic devices become increasingly prevalent, the issue of powering the device in a human implant is a major concern. Wirelessly transferring power to the implant has been thought of implemented, but using cerebrospinal fluid in the brain as powerhouse was something

recently thought about and is being developed - which again requires flexible circuits.

B. Biomedical Implant

Flexible circuits have demanding applications in biomedical wherein they can easily replace organs which have stopped functioning or with limited functionality. They can be easily folded as desired and therein they have advantages over rigid PCB based circuits.

C. Flying robots

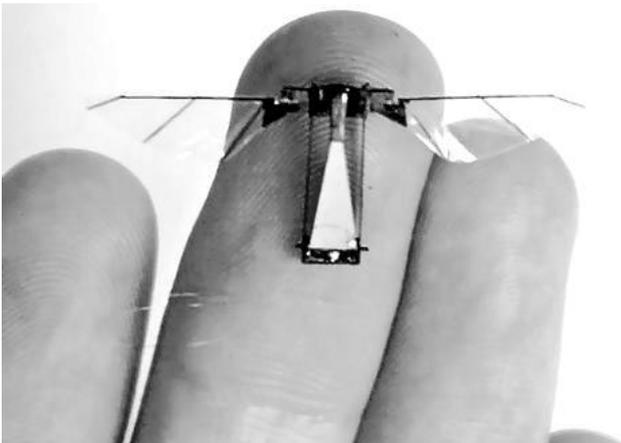


FIG.8. FUTURE APPLICATIONS FOR FLEXIBLE ELECTRONICS

Weight is at a premium for any flying machines or robots. A drop in magnitude of weight could give similar ratios to the internal combustion engine and the jet engines (if incorporated) in the UAV's. Modern flying robots are often made with lightweight composites. This makes them vulnerable to damage from lightning bolts. Coating aircraft with a conducting polymer can direct the electricity directed away from the vulnerable internals of the UAV's.

The typical ornithopters with wings can be developed with electronics embedded inside the wings itself, giving the robot the lesser density and occupy lesser area.

VIII. CONCLUSION

The field of flexible electronics is quite an advancement and the application in electronics and

robotics is certainly something which would push the boundaries further in engineering and technology. The circuit was actually implemented with flexible electronics but more research can be done in this field with respect to the substrate and the ink which can be used for most reliable circuits. The low-cost, flexible nature and reduced volume occupied by the circuit are the advantages compared to rigid PCB circuits. The concepts on flexible LCD can be further exploited to make user-friendly applications.

The disadvantages of flexible circuits being possibility of broken trace while inkjet printing or while folding the circuit. Hence designs should be implemented to minimize such a possibility.

IX. ACKNOWLEDGMENT

The authors would like to thank Prof. Uma Rao and Prof. Snehal Gawali whose inputs were highly valuable. They would also like to thank other professors of Shah and Anchor Kutchhi Engineering College whose constant support made this research a success.

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