Design and fabrication of sensor module on flexible PCB using UV film

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Abstract* — A commercially available option for confirming the shape of a wearable system, supporting electronic sensing and flexible connectivity is a flexible PCB that employs UV technology. Flexible electronics and sensors are a crucial enabling technology for the creation of wearable and geometry adaptive devices, which is in line with the current trends towards Industry 4.0 and Internet of Things (IOT). In this study, a novel method for creating a printed circuit board that is incredibly thin and flexible (PCB) is presented. Active and passive electronic components are increasingly integrated within the printed circuit board itself which becomes more than a mere support for components. The printed circuit board is evolving to become a central supporting element in solving construction problems in electronics. Flexible PCBs were initially designed as a replacement for traditional wire harnesses. In conclusion, the manufactured sensor shows good flexibility, excellent sensitivity, finishing and ability to match various applications for flexible sensors. However, alongside the increasing innovative applications, flexible-circuit technology will provide product design which increases functionality, improves circuit density, provides higher connectivity, better environmental performance, lower cost and flexible circuitry using UV film. Also fabrication of the proposed sensor on a flexible PCB will be done using UV exposure and parametric analysis of the fabricated sensor will be done. Flexible PCB lowers the cost of wire connectivity by 70 % and electric interconnection by 65%.

***Keywords:* PCB (Printed Circuit Board), UV Film, wearable, exposure, Fabrication, IOT(Internet Of Things)**

INTRODUCTION

The term” flexible printed circuit board” (also known as ”Flex PCB” or ”flexible printed circuits” or ”FPC”) refers to an advanced way of printed circuit board (PCB) that can be bent, twisted, or bent into any desired shape as shown in Figure 1. Flex circuits are composed of flexible substrate, usu- ally polyamide or polyester.[1] The flexible-circuit substrate laminate, which can be used to connect electronic equipment, is often made up of such materials.[2], stretchy conductors made of conducting polymers are based on solid stretchy molecules.[3] Additionally, it is capable of having electronic components connected to it directly using solder or conductive glue. Flexible circuitry is well-positioned to fulfill the promise of 21st -century electronics as the needs of modern electronic systems call for greater functionality and circuit density, higher inter connectivity, better environmental performance and all at lower cost [18,4].

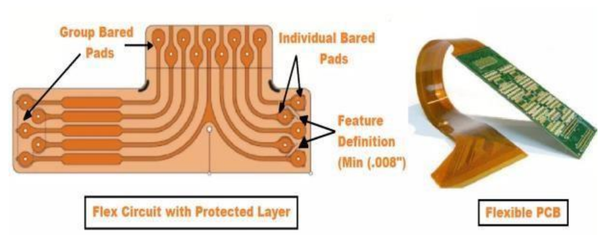

Fig. 1. Flexible Printed Circuit Board.

The objectives of this project are:-

1) To study different parameters of existing technology of PCB fabrication
2) To design and simulate sensor module on PCB simula- tion tool
3) To fabricate the proposed sensor module on flexible PCB using UV exposure
4) To perform the parametric analysis of fabricated sensor module integration and test it .

Using an ultraviolet (UV) film, flexible PCB regions that are rigid-flex can be sliced. PCBs vary from one another in terms of their working frequencies, speeds, current powers, suitability for usage in the home or commercial sectors, medicinal uses and many more. Importantly, flexible printed circuits have made their way into our daily lives through the aforementioned uses. Traditionally used to replace wires, obvi- ating the necessity for intricate wire harnesses, and substituting expensive and with wired assemblies becoming more and more complex, flexible circuits offer an easier and often a far more economical connectivity technique. We researched some research papers and found that there were certain limitations of rigid PCB's. After studying these research papers we finalised our topic, which is "Design and fabrication of sensor modules on flexible PCB using UV film". Circuit boards, known as flexible PCB's, are composed of flexible substrate materials and provide several advantages over conventional rigid PCBs. The advancement of product manufacturing, which includes lightweight design, scalability, multi functionality and assem- bly densification, has led to higher standards being established for printed circuit board (PCB) technology. The production processes include the following steps:

- Lighter weight
- Dynamically bendable
- Has ability to assemble 3D interconnections
- Greater design freedom for mechanical and electronic systems
- More efficient space utilisation

Flexible circuit boards are the ideal choice for applications that call for improved performance, high accuracy, precision and regular flexing. The flexible boards can be bent into any shape, so they are frequently employed for static and dynamic flexing applications.Circuit boards used for static applications only allow minimal flexibility, whereas dynamic circuit boards are designed for frequent flexing.

METHODOLOGY

A. *Fabrication Materials and Equipment's*

The materials that have been used for the fabrication are as shown in (Figure 2):

- OHP sheets - They are used for thermal transfer print- ing.[1] The sensor has been mounted on this flexible plastic sheet. It resists melting even at temperatures of up to 150 °C.
- Kapton Tape - general purpose tape with polyamide film and silicon adhesive. It is often used as an insulation and protective layer over electrostatically delicate and fragile components during electronic fabrication [18].
- Copper foil - The electrodes for the flexible sensor are made out of this foil and bonded to the flexible plastic substrate [7].
- Photosensitive film - This film is made up of a light - sensitive layer on a thin substrate. The copper foil has been laminated with this film for further processing [1,6].
- Ferric chloride - Ferric chloride is used as an etch- ant because it can selectively etch copper while not affecting the substrate or other materials on the PCB. The etching process is done by applying a photo resist to the copper foil, exposing it to UV light and developing the image.Sodium carbonate mono hydrate - It is used as a developer solution [1].
- Film-Maker - It is a counter top unit that functions both as a negative, making contact printer and an illuminated Artwork table for Circuit Artwork taping, film and false inspection [19].
- UV light box - This box contains UV lamps that are used to transfer the electrodes' printable shapes on the laminated copper foil. A table-top, two side exposing machine for high-precision PCB exposure. The tiny footprint consumes the least amount of space and power.
- Developer - It is a tabletop unit that allows you to dye and create PCB laminates in the same machine [6,7].
- Film Exposure Source - It is an illuminated art work table for circuit artwork, taping and inspection.

Fig. 2. Fabrication Materials

B. *Fabrication Process:*

1) Software design - Flexible PCB design, including schematic creation, PCB design, analysis, Gerber file generation, and circuit simulation, is done using a combination of Altium Designer, EasyEDA, and Pro- teus Suite. Multi-layer design, embedded components, version control, design collaboration, and supply chain management are among the features offered by Altium Designer, while EasyEDA is a web-based tool with an intuitive user interface, a sizable component library, and an integrated cost estimator. For simulation and graphic analysis of the circuit, Proteus is used.
2) Printing The Design - When designing a flexible PCB, it is important to select the right ink and printing method, ensure that the print layout won't flex the PCB and cause damage, place components or traces in

specific locations for flexibility, use specialized printing techniques, and take into account the overall PCB design. [5]

3) Copper Lamination - The flexible substrate and copper foil must be delicately adhered during this step in order to provide a clear surface for the lamination. With the help of a hot laminating machine, a thin layer of a photosensitive film was then laminated with the copper to improve adhesion. [6,7]
4) Exposing process. - This step involves aligning the semi-transparent printed film with the laminated copper and using the UV box to expose them to UV light. The exposed film has been immersed in the developing solution while being shaken in order to dissolve the lamination's unexposed area while keeping the exposed area covered. While the areas of the lamination that are lying beneath the printed area are not exposed to UV light, the exposed area will be hardened by it. [19]
5) Developing process - The exposed film has been submerged in the developing solution while being shaken in this stage to dissolve the lamination's unexposed portion while keeping the exposed section covered.[14]
6) Etching process - In this phase, the produced film was immersed in the etching solution while being agitated to remove the unmasking copper area. [20] The etching solution was made by dissolving approximately 50 g of ferric chloride in 100 ml of water, and the etching solution has a 50 percent concentration.

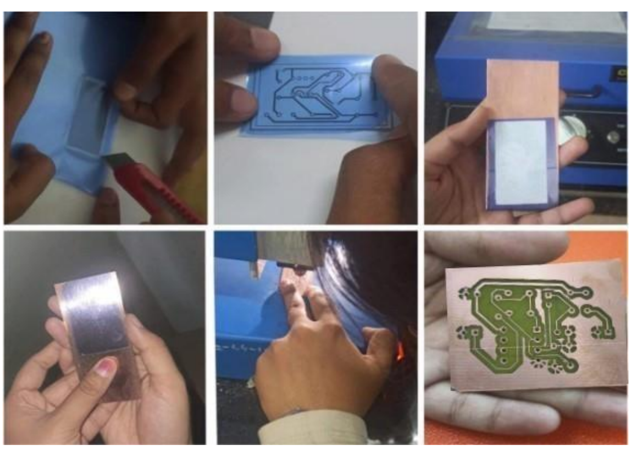

Fig. 3. Fabrication Process

C. Evaluation

According to the materials' respective sales volumes in the FPC market, polyamide is the flexible-circuit dielectric of choice for approximately 75-80 percent of the applications.Owing to their toughness and resistance to heat and chemical damage, they are more expensive than polyesters. Table I summarizes the evaluation of the flexible PCB materials.

TABLE I
EVALUATION OF FLEXIBLE PCB MATERIAL

Property	Units	POLYAMIDE (Adhesive Based)	POLYAMIDE (Adhesiveless)
Thickness Range	mil	2 - 3.5	2 - 3
Tensile Strength	psi	24,000	48,000
Break Elongation	%	67	46
Tensile Modulus(@25°C)	100,000 psi	4.2	0.6
Tear Intention Strength	Ib/in	995	600 - 1200
Tear Propagation Strength	g/mil	6	17

High flexibility, strong flexing and electrical properties over a broad temperature range, high temperature resistance, and resistance to soldering conditions are all characteristics of polyamide films.

Flowchart - The following flowchart (Figure 4)represents the workflow or process of Flexible PCB manufacturing:

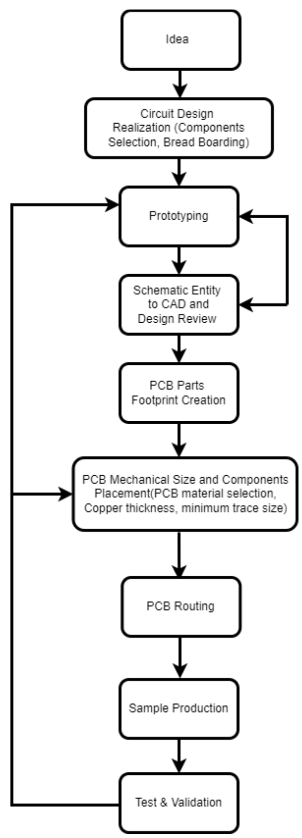

Fig. 4. Flowchart of Flexible PCB manufacturing

The typical PCB design workflow is focused on taking an engineering design, completing a physical PCB layout, and getting the finished design ready for manufacture.

- Process of Flexible PCB design starts with an idea presentation.

- Once idea finalization is done we move towards circuit design realization with the help of component selection and bread boarding. It needs bread boarding in order to easily connect electrical components so that you can test your circuit before permanently soldering it together and then making the connections then convert it into PCB design.
- Flexible PCB prototyping is the process of creating a functional circuit from a theoretical design in order to verify if it performs as expected and to provide a physical environment for troubleshooting it if not. Testing and validation can be done after prototyping.
- CAD allows for the development, modification and optimization of designs to design and manipulate drafting of schematic design virtually.
- After the PCB design is finished, the hardware is tested on samples under a variety of conditions and limitations to ensure quality and durability. The hardware is examined for its various properties, including signals, voltages, amplitude, magnitude, temperatures, heat conditions, and power consumption.
- The final prototype for manufacturing is authorised when it completely satisfies the criteria. The prototypes, design files, test reports, estimates, and a comprehensive list of future recommendations is completed at this point.

RESULTS AND DISCUSSION

The LM35 sensor operates on the fundamental principle of a diode to measure the value of temperature. When the temperature rises, the voltage across the diode rises at a specified level. An ac signal that is directly proportional to temperature can be produced by appropriately amplifying the voltage change.When an temperature variation is linear, it is possible to describe the connection between measured resistance and temperature change as follows:

$$V_{out} = (V_{outLM35} - 80mV) * R2/R1$$

We can easily explain what is happening if we take the sensitivity voltage as V1 and the output of the LM35 as V2, then output voltage given by using following comparison:

$$\begin{aligned} V_{out} &= +V_{sat} \text{ when } V1 > V2 \\ &= -V_{sat} \text{ when } V1 < V2 \\ &= 0 \text{ when } V1 = V2 \end{aligned}$$

Based on the equation between temperature and resistance, the inner resistance of a temperature sensor can be determined.

*1) **Temp Vs Resistance :-:*** Following Temp vs Resistance Graph(Figure 5) shows the relationship between resistance of the circuit changes with temperature:

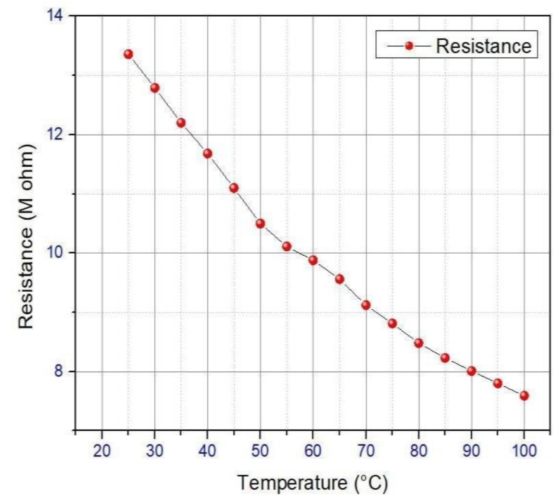

Fig. 5. Temp vs Resistance graph

A temperature versus resistance graph for a flexible printed circuit board (PCB) typically shows how the resistance of the circuit changes with temperature. This graph predicts the performance of the circuit in various temperature environments and ensures that it operates within its specified temperature range. The graph is typically plotted with temperature on the x-axis and resistance on the y-axis. As the temperature increases, the resistance of the circuit also increases. This relationship is due to the temperature-dependent electrical properties of the materials used in the circuit. By analyzing the slope of the graph, one can determine the temperature coefficient of resistance (α) of the circuit, which is a measure of how much the resistance changes per unit change in temperature. A low α indicates a circuit that is relatively insensitive to temperature changes, while a high α indicates a circuit that is more sensitive to temperature changes. In general, the temperature versus resistance graph is useful for characterizing the performance of flexible PCBs and can help optimize the circuit for specific temperature requirements.

2) **1000/T**/K-1 **Vs ln(R) :-**

The plot of 1000/T (in Kelvin) versus the natural logarithm of resistance (ln(R)) is a common representation of the electrical behavior of flexible circuit boards, where T is the temperature and R is the resistance. This plot, known as the Arrhenius plot, was used to analyze the temperature dependence of the conductivity of the material. The activation energy is an indicator of the energy required for an electron to travel through the material, and is calculated from the slope of the plot.

The 1000/T/K-1 Vs ln(R) graph (Figure 6) was used to analyze the performance of the material and predict the long-term behavior of the flexible circuit board.

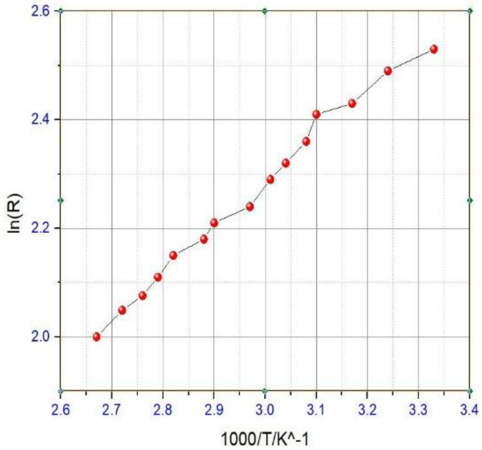

Fig. 6. 1000/T/K=1 vs ln(R) graph

The intercept of the plot provides information about the pre-exponential factor, which gives the frequency of the electron hopping events. This plot is used to characterize the material's performance, identify any degradation mechanisms, and predict the long-term behavior of the flexible circuit board. Films made of polyamide and polyester are two materials that receive the utmost consideration.

3.3 Heart rate (in Amp) Vs time :-

The circuit system for the sensors consisted of an analytical circuit and a digital circuit, and a schematic diagram is shown in Figure 7. The sensor signal is amplified and filtered using an analog circuit. The band pass frequency of the analog circuit for monitoring waveforms is set at 0.1-25 Hz since the pulse signal's frequency range is roughly 0.1-20 Hz. To reduce the distortion of the pulse peak, the band pass frequency for Pulse Width Modulation (PWM) measurement was selected to be between 0.1 and 40 Hz. A voltage reference chip, which is needed to provide a reference voltage, can be used to adjust the output voltage between 0-3.3 V.

The Heart rate (in Amp) vs. time graph (Figure 7) was plotted to analyze the performance of the material and predict the long-term behavior of the flexible circuit board:

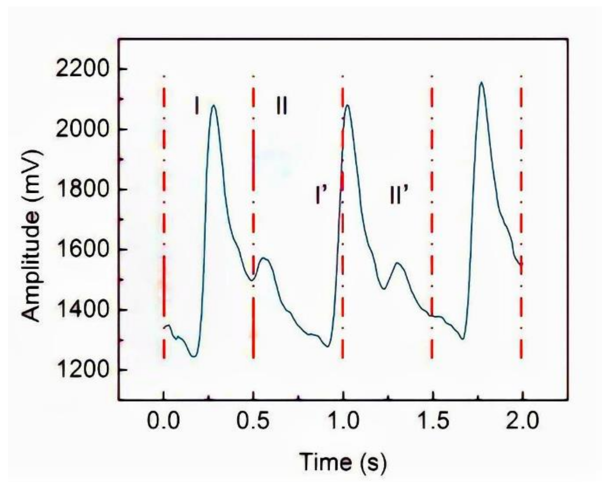

Fig. 7. Amplitude (mV) Vs time graph illustration of current (l,ll) and next calculation intervals (l', ll')

In this case, we extracted the pulse characteristic points, which is essential in the time delay calculation. We extracted pulse percussion wave peaks. We set the time interval S based on a typical pulse length. The total of two intervals is 1.2–1.5 normal pulse length to ensure that there is at least one pulse peak in each interval.

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Following table represents the major difference between Rigid PCB vs Flexible PCB:

Properties	Rigid PCB	Flexible PCB
Flexibility	Not Flexible	Flexible
Stability	More stable	Less stable
Operating Temperature	High	Moderate
Space and weight	More	Less
Dielectric strength	Same	Same
Durability	High	Moderate
Performance	Good	Better
Fabrication Time	Less	More
Cost	Low	Moderate

Finally, the proposed system achieved an overall performance of 75 % with Flexibility of 70 % and Stability of 80 % in the Flexible Circuit.

Conclusion

In this work, a systematic fabrication approach for flexible sensor module has been given. The finished sensors have

various designs, display good flexibility and finishing.Due to the excellent flexibility of all the sensing materials utilised in the creation of the sensor, the flexibility of the substrate used has an impact on the flexibility of the sensor module. The fabrication method exhibits significant benefits by producing sensors that can cover objects with even irregular shapes and by enabling the embedding of sensors for some applications that use materials which don't interact with the developing and etching liquids used in fabrication process. The performance of the fabricated sensor module seems to be near from that the conventional sensor module in the market.

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