An introduction to flexible electronics: Manufacturing techniques, types and future

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Abstract. Flexible Electronics is an emerging technology in the fields of electronics. These are electronic circuits made on substrates which can be modified into various shapes. It can be rolled or twisted with minimal or no effect on its electronics components and its function. Flexible electronic components are usually made of a bi-layer of thin substrate which can be either plastic, metal or textile or any other suitable material with a second layer of active electronic component. Wide range of its application in solar cells, aerospace and medical fields have increased its demand by many folds. Flexible electronic circuits play a major role in components where density, availability of space, and weight of the material has to be taken into consideration. The following is the review of the current status of it the modern electronic industries, its manufacturing process, its application in various technological fields, and the role it will play in the future

1. Introduction
Advances in thin film technologies used in various materials and devices have given rise to many developments in the field of flexible electronics. Flexible electronic circuits sometimes also called as flex circuits, is the technology where the electronics circuit is mounted on flexible substrate like polyimide, polyether ether ketone (PEEK) or transparent conductive polyester [1]. To narrow down the radius of a silicon substrate and to achieve more flexibility various kind of etching methods are being used. [2-11]
Flex circuits can be used for sensors in bed-sheets for the real time detection of heat, humidity, pressure, of human body. [12]

Flexible circuits could replace the bulky solar panels that need to be installed on the roof tops. These circuits can instead be incorporated with the fabric of the curtains and could be stuck on the window panes and hundreds of such structure together can work as normal solar panels. Flexible solar cells can and are being used to power satellites. These are lightweight, flexible, that can be rolled up and hence deploying these become very easy. These can also be sewn into backpacks and outer wears. [13]

![Figure 2](source: reeves.com)

Flexible circuits are widely used in electronics papers, which are used in e-readers, smart cards, electronics shelf labels etc. However, glass backplane hinders the flexibility of e-readers. [14]. Flexible Circuits are used for the development of PIFA antennas, where thin film gold is directly deposited on elastomeric substrate. [14]

2. Manufacturing and types of flexible circuits

Basic materials used for the manufacture of flexible circuits are; Base material, Bonding adhesive and metal foil. A flexible polymer film acts as the base material which provides the foundation for the laminate. Most flexible films have the thickness between 12 µm to 125 µm. The thinner the film the more flexible it is. The thicker the film gets the stiffer it becomes. Materials like polyester (PET), polyimide (PI), polyethylene naphthalate (PEN), polyetherimide (PEI), and various fluropolymers (FEP) and copolymers are used for the base film. Polyimide films are preferred over the other materials due to their physical and chemical properties. Adhesives are used for creating a laminate. Same as the Base materials, Bonding adhesives too have various range of thickness. The most common element used as a conductive material in a flexible circuit is the metal foil. The metal foil is the material from which the circuit paths are normally etched. Copper foils are the most preferred ones, since they are both cost effective and have excellent physical and electrical properties.

2.1. Manufacturing techniques

Flexible electronics deal with circuit designed using Thin Film Transistors (TFT). There are multiple TFT fabrication techniques available today incorporating different semiconductor material. The primary ones are discussed in the following sections.

2.1.1. Amorphous silicon technology

Hydrogenated amorphous silicon (a Si:H) TFTs are being used in active-matrix LCD displays. a Si:H TFT based integrated drives are best suitable for applications where the images need to be updated not so frequently such as on advertising boards, applications which have the maps etc. [15-17]
2.1.2. Polysilicon technology
Polysilicon Thin film transistors are made at higher temperatures. Re-crystallisation of a Si:H material, using a laser, is used to manufacture these transistors. These TFTs can have mobilities greater than 100cm²v⁻¹s⁻¹ and very stable threshold voltages. Poly-Si TFTs can be used to develop CMOS digital circuits. [18]. However, this process is not very cost effective. The cost of the substrate and overall production is quite high.

2.1.3. Organic thin film transistor
Organic semiconductors like Pentacene, TIPS Pentacene etc. can be used to produce organic TFTs. Solution process or vacuum evaporation process can be used to manufacture these semiconductors at low temperatures.

2.1.4. Mixed oxide thin film transistor
IZO, IGZO are examples of metal oxide thin film transistors. These have better mobility, stability and also higher current density as compared to a Si:H TFTs. Metal oxide TFTs are also transparent, so they are of a great use in manufacturing the transparent flexible circuits. [17]

2.1.5. Hybrid (CMOS) technology
CMOS technology is the fastest available technology currently. There is power loss for this technology is significantly low. CMOS circuits are implemented using p-type and n-type TFTs on the same substrate. These types of circuits display low power consumption and leakage current [18-19]. According to a research report published by Flexible Display Centre in collaboration with University of Texas at Dallas showed that these CMOS logic circuits are more stable as compared to a Si:H TFT circuit. This is because the V(t) of the a Si:H TFT shifts in positive direction with electrical stress while the organic TFTs shift negative as shown in Figure 3.

![Figure 3. V(t) shift- a –Si: H nMOS and pentacene pMOS [18]](image)

2.2. Types of flexible circuits
Flexible circuits can be divided into several categories based on their construction; hence they have difference in their structures. Below listed are some of the common structure of flexible circuits:

2.2.1. Single sided flex circuits
The most basic of flexible circuits. A thin sheet of copper is laminated by a flexible layer of polyimide film. Then chemical etching is done on the copper layer, producing a circuit pattern according to the
design requirements. To protect the circuit from environmental factors and also to provide insulation, a polyimide overlay is added.

2.2.2. Double sided flex circuits
As the name suggests, double sided flex circuits have two conductive layers, one on each side of the base layer of polyimide within the circuit. Circuits patterns can be traced on both sides of the substrate film. Connections can be made between both the plates through holes between them.

2.2.3. Multilayer flex circuits
Several single-sided or double-sided circuits are combined to realize a multi-layer flexible circuit. The multi layers are sometimes continuously laminated. Continuous lamination is not suitable when maximum flexibility is required.

2.2.4. Rigid flex circuits
These circuits are a combination of both flexible and rigid circuits and hence have the quality for both. These circuits are both stable and flexible at the same time. These circuits can have various shapes. They also have better heat dissipation, and are quite resistant to ultra violet rays. [13]

3. Future of flexible electronics
Increasing demands of gadgets like smart watches, smart phones, e-book reader, thin-film photovoltaics, printed sensors has pushed the market for the flexible electronics to a new high. Flexible electronics circuits technologically advanced and has a low cost of production as compared to rigid electronic items.

However, the flexible electronics has its own drawbacks. It has a high investment cost, the assembly of a flexible electronic circuit is a complex task and hence requires a high level of expertise in this field. There is still not adequate facility for the manufacture of flexible electronic gadgets and devices on a large scale. Hence all these factors combined with the increasing demand and advancement in technology will affect the market of flexible electronics in the future. Figure below shows the possible demand for flex electronic circuits in the time 2019-2027.

![Graph showing demand for flexible electronic circuits](source: maximizemarketresearch.com)

Figure 4. Global Flexible Market analyzed by region (2019-2027) [Source: maximizemarketresearch.com]

It is estimated that the revenue of flexible electronics can reach a value of around 300 USD by the year 2028. [20] Flexible electronics is a technology very much in demand these days. Countries all over the world are working to make flexible electronics more and more useful for us. However, research in this field depends from region to region. Like in the United States, research is primarily motivated by its use in the military and the Asian countries are majorly investing in making flexible displays.
4. Conclusion

Flexible circuits have evolved a lot in the last decade. These circuits can be used to make a phone which we can wear. Back in 2008, flexible electronics had a stretchability of around 70 percent while keeping their conductivity the same; today, the stretchability has increased to around 1000 percent of its original length. New innovative technologies are paving the way for more advanced and consumer friendly flexible electronics.

5. References

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