Fused Filament Fabrication of Electronic Circuits and Components with Conductive Thermoplastics

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Abstract - *Fused Filament Fabrication is a method of additive manufacturing which uses a continuous filament. Additive manufacturing refers to the type of manufacturing wherein objects are manufactured by laying technique usually using a STL file. Most intricate and complex designs can be obtained using this method. With Industries rapidly growing, it's not very far in the future when most of the manufacturing will be done by this method. This paper is a study of the requirements, process, outcome and future scope of manufacturing electronic components and circuits by Fused Filament Fabrication using conductive metal-polymer composite.*

Key Words: **Fused Filament Fabrication, Additive Manufacturing, Conductive metal-polymer composite.**

1. INTRODUCTION

Additive manufacturing is the joining of materials to make objects using a stereolithography file. This technology is also referred as rapid prototyping, digital manufacturing and layered manufacturing. Additive manufacturing allows the consumer to make the object exactly as per requirement. Most of these designs cannot be achieved by conventional methods. This is one of the features of Additive Manufacturing that has fuelled its growth.

The Fused Filament Fabrication is one of the most popular techniques of Additive Manufacturing. The reason for this being is its reliability, safe fabrication process, cost efficiency and availability of materials. The basic principle of operation of Fused Filament Fabrication offers the usage of variety of other materials depending on the temperature range, size and strength. As long as the material is available, it is possible to develop any object of required size and shape.

Traditionally, Fused Filament Fabrication had been able to build parts only using thermoplastics but modern Fused Filament Fabrication can process parts in composite materials such as Polylactic acid, stainless steel etc.

On the other hand Electronics is generally high volume production which is to be of low-cost and of high-performance. The recent development of tools for 3D printing has created interest in using similar techniques to the development of 3D printed electronics and circuits. Integrating electronically functional materials with the potential of additive manufacturing can enable the production of multilayer circuit boards, 3D antennas and passive components such as Resistors, Inductors and Capacitors.

2. METHODS

2.1 Materials

Multi 3D Electrifi Conductive Filament which is a metal-polymer containing copper and polyester. Painter's tape on the heated bed for proper adhesion was used. Filaments used:

- Polylactic Acid (PLA): PLA is a thermoplastic derived from renewable resources like corn starch, sugar cane etc. It is a biodegradable and bioactive thermoplastic. Due to its lower printing temperature, it is easier to print with and hence best suited for parts with finer details. The density and print temperature is 1250kg/m^3, 190-210◦C
- Conductive Filament (Metal Infused): Metallic Filaments are made by infusing PLA with very fine metal powders; here Cu is used in the neighbourhood of 4:1 ratio.

2.2 Fabrication

To prevent the contamination of the conductive and non-conductive filaments during dual extrusion that will cause interruption of conductive traces with non-conductive material or shorting between conductive traces, is to extrude both the filament using a single nozzle. It is achieved by printing a single filament at a time by programming it to retract out completely from the hotend and a new filament is fed into the extruder to be printed. Precaution is to be taken to clear the old filament by purging 30mm of the new filament. Autodesk Fusion360 was used to create 3D models of components, which were then imported to Cura (by Ultimaker) slicing software to generate 3D printable gcode files. The printing parameters used are listed in Table I.

For testing it practically, we have used a custom built printer which consists of a single extruder and runs on Marlin Firmware.

Material	Print speed (mm/s)	Extrusion Temperature (◦C)
PLA	40-60	190-210

(Non-Conductive)		
Electrifi (Conductive)	10-30	130-160

Table -1: Printing Parameters

2.3 Printing using single extrusion

To obtain required 3D electronic component we use the following programs

- Computer-aided design software (Fusion 360): 3D CAD, or three-dimensional computer-aided design, is technology for 3d design, which replaces manual drafting with an automated process. Used by architects, engineers, and other professionals, 3D CAD software precisely represents and visualizes objects using a collection of points in three dimensions on the computer screen. It provides diagram file in the form of .dwg format which is then converted into STL file, which acts as input to slicer software.
- 3D slicer software (Cura): It is a platform used to convert STL file into g-code file which is in the form of machine language. This tool provides setting for the printer. Such as infill, support, speed flow rate of filament.

The following are the steps to use multiple filaments in a single extruder

Now we need to change the required temperature and other settings for the appropriate filament. This will cause printer to pause and at this stage we need to replace the filaments. After this process 3D CADE file is converted into layers. Refer Figure 1

Cura → Extensions → Post Processing → Modify gcode

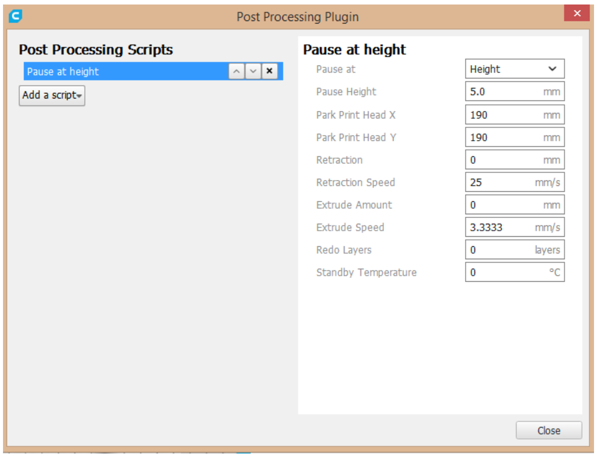

Fig -1: Window to configure pausing; to change filament

2.4 Characterization

For testing the Electrical characteristics of the filament (IV) the filament cannot be directly connected to the probes of the multimeter, as the resistance of the probe is way greater than the filament resistance itself. So the prescribed method is to use screw terminal, silver paste or short piece of melted filament as shown in figure 2

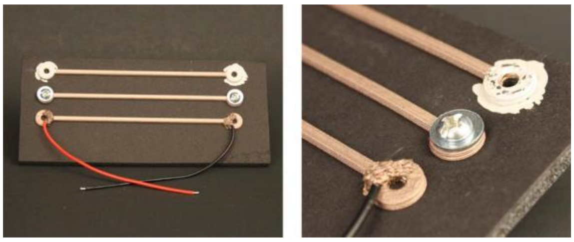

Fig -2: Possible connections to find the equivalent resistance

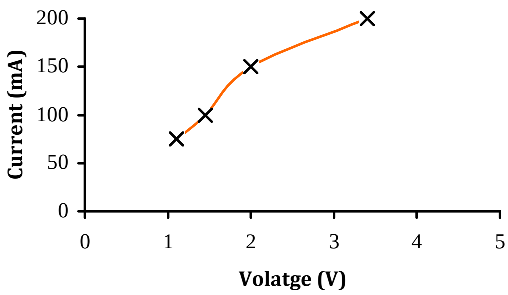

Chart -1: IV Characteristics

Upon the above calculations it was found that the resistivity is 0.006 Ω cm. Now calculating the resistance per centimetre is.

$$R = \rho\ (l/A)$$

Taking,

$\rho = 0.006\ \Omega$ cm

$l = 1$cm

$A = 0.175(\pi/4)$

$$R = 0.006[1/0.175(\pi/4)]$$

$$R = 0.25\Omega/\text{cm}$$

3. RESULTS AND DISCUSSIONS

The three of the most basic electronic components are resistors, inductors and capacitors. By integrating these components, a wide range of electronic circuits can be fabricated including sensors, oscillators, voltage and current dividers, relays, crossovers, transformers, Antennas and filters.

3.1 Connections

The PC Board can either be printed from as non-conductive filament or it can be a pre made. The electrical connections can then be laid upon and the components can be attached by softening the filament with a heated gun at 100◦C and pressed down firmly. The contact resistance can be lowered by adding a bit of silver paste to the point of contact between the IC and the filament after pressing the components into the filament rail. Figure 3 and 4 shows the methods of attaching the electronic components.

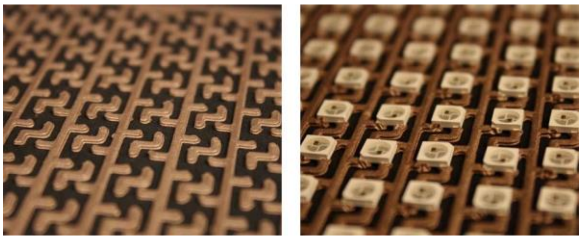

Fig -3: Circuit (left), LEDs press fitted by softening filament (right)

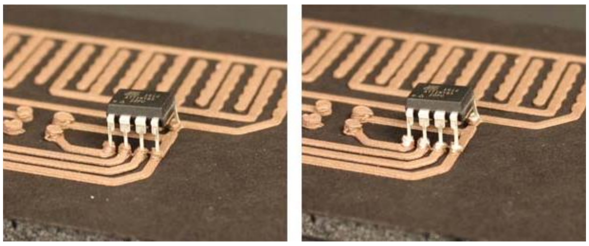

Fig -4: IC fitted with softening (left), adding silver at contact (right)

3.2 Resistor

The resistive element is achieved by altering the dimensions of the resistive element from which it is made by simply varying the cross-sectional area of the printed trace; resistors with values ranging from 1 to 1K can be obtained. Chart 1 shows a linear line obtained from the results which follows Ohms law. Figure 5.

3.3 Inductor

Air-cored Inductors can be printed which are commonly used in RF circuit. Different inductors consisting of different number of turns can be printed where PLA as an insulating dielectric material in the structure. Figure 5.

3.4 Capacitor

Parallel plate capacitors are 3D printed in the conductive material, and PLA as in the inductor is used as the dielectric medium. The overlapping dimensions of the parallel plate and the vertical separation distance can be set to required dimensions. The capacitance can be easily changed by altering the four parameters such as Geometry, Permittivity of Dielectric, area of the plates and the Distance between the plates. Figure 5.

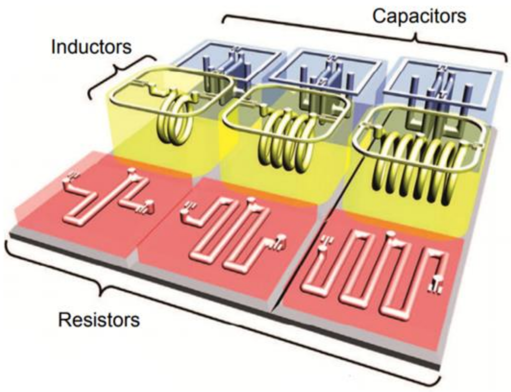

Fig -5: Capacitors (blue), Inductors (yellow) & Resistors (red)

4. CONCLUSION

This paper demonstrates the printing of Electronic circuit and components in one go. More and more advancement in 3D printing enables us to develop many functional electronics and products. For now, comparing this technology with the traditional PCBs is not justifiable as Fused Filament Fabrication of electronic circuits and components by conductive thermoplastics is still in primitive stage. But the day is not far away where people in their own houses will start printing mobiles and other electronic devices without any complex machines.

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