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RESEARCH ARTICLE

3D - PRINTED MULTILAYER PROCESSES FOR LIGHTWEIGHT WEARABLE AND FLEXIBLE MICROSYSTEMS

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Abstract

Three-dimensional (3D) printed microsystem has significance potential for ubiquitous and lightweight wearable devices. Here we present a metal deposition process for 3D microsystem integration accomplished through evaporating, sputtering and electroplating techniques. To provide a proof of principle for the approach, we demonstrate 3D printed two layers microsystem of Electrocardiogram (ECG) signal detection on polypropylene photopolymer (RGD450) substrate. Furthermore, the presented process can be extended for multilayers structure enabling realization and miniaturization of complex systems in planar and non-planar structures. Utilizing concepts of 3D printing with the proposed process and enhancement of adhesion properties provides the ability of implementing printed electronics in wide range of substrates material.

Introduction:-

Development of lightweight wearable devices 12 and replacement of conventional fabrication methods for electronic devices 34567 have led to 3D-printed prosthetics 8, dental implants 9, bionic ears 10, compound eye system 11, antennas 12 and Li-ion microbatteries 13. However, most of 3D printed microsystems use Cu conductive ink requiring high curing temperatures to lower the resistivity 14 15. The copper films offer approximate bulk resistivity of 1.67 $x10^{-8}$ Ω.m if the thickness of film is 49 nm or larger 16 with no curing temperature needed after deposition. Broader types of materials on plastic substrates with evaporation techniques 1718 and recent development in 3D printing machines, with ability to print very high-resolution geometrics with different materials, including Acrylonitrile Butadience Styrene (ABS), flexible filaments, High Impact Polystyrene (HIPS) and carbon fiber filaments 19202122 are important.

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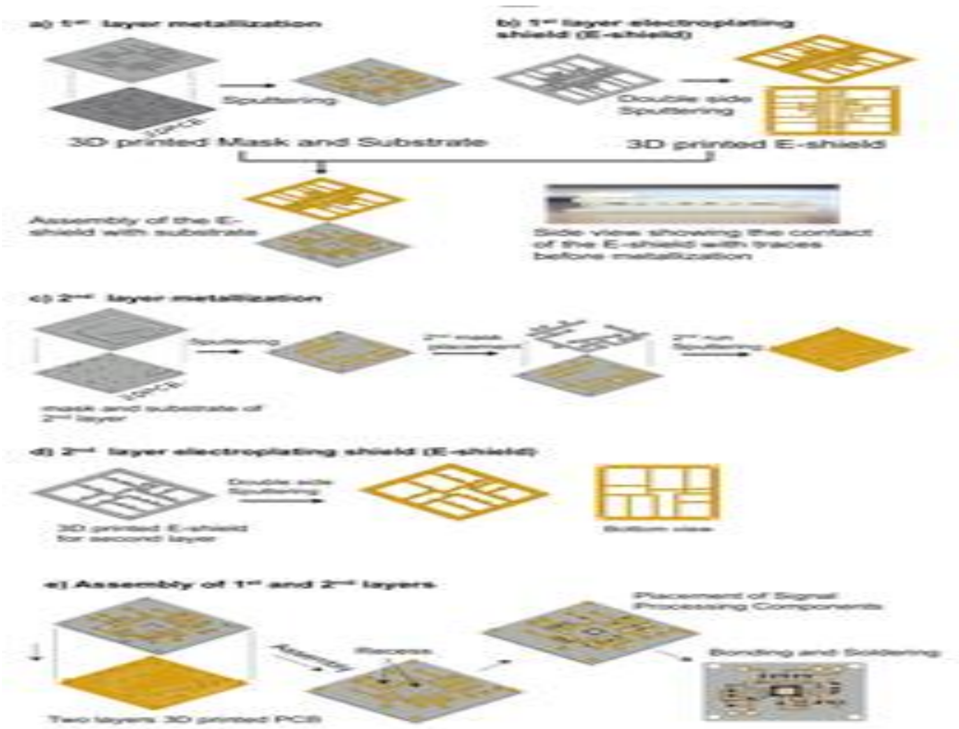

Fig. 1: Concept diagram of the developed 3D-printed microsystem processes

This letter reports, novel 3-D printed metallization processes developed for multilayer Microsystems, using lightweight material on planar and non-planar surfaces, for the first time. It has following unique features: a) self-aligned 3D-printed shadow mask designed for patterning metal interconnects, b) a temporary connection between isolated metal segments created by a 3D-printed metalized structure for electroplating process, and c) vertical interconnect access (via) process created and metalized to enable electrical connection between multilayers of the Microsystem for miniaturization. This process can be adapted in PCB (Printed Circuit Board) manufacturing as it offers smaller fabrication steps than conventional PCB fabrication and it is highly desired for fabric-embedded devices 23 .

Design And Fabrication:

As shown in Fig. 1, this letter, for the first time, addresses the following aspects for development of 3D Microsystem process: 1) 3D printed shadow mask with customized size apertures utilized for fabricating sharp patterns of conductive traces through physical vapor deposition (e-beam evaporation and sputtering techniques). The shadow mask helps patterning of conductive traces for electroplating process (a). 2) After evaporation, the metalized substrate (top), placed in holder's recess for better alignment. The electroplating produces the desired thickness of the patterned metal (b and d). 3) Multilayer process through metalized structures provides vertical interconnect access for implementation of a compact 3D Microsystem (c).

The process of this letter provides metal interconnects on plastic substrates (1mm thick with recess depth of 0.8 mm) more efficiently than conductive inks for the following reasons; (a) by not requiring curing at high temperatures to enhance conductivity, it is suitable for a wide range of polymer-based substrates, and (b) it produces lower resistivity interconnects. For better access the chip pads, it was mounted bottom-up position. After checking the electrical connectivity, the passive components and IC chip were soldered and tested.

The proposed process involves three metallization techniques: (1) e-beam evaporation for thin film patterns, (2) sputtering for step coating of the knobs structures in the bottom layer, and (3) electroplating for further increasing the thickness of the deposited metal. The deposited films are:

1. 100 nm Ti to enhance adhesion between the surface of the substrate and the deposited gold/copper.

2. 500 nm; Au for wire bonding or Cu for soldering.

Metal films are sputtered on the surface of the sample with 100 nm Ti and 500 nm Au at $2x10^{-6}$ Torr with deposition rates of 1.5 and 7.6 nm/s, respectively. As the thickness of deposited film is not sufficient for soldering process, electroplating process is used for achieving 10 microns thickness of metal interconnects. Based on initial demonstration, it's noticed that sputtering provides a better step coverage on the second layer substrate than evaporation. This is critically important for vertical interconnect access through via holes.

Discussion and Conclusion:-

The deposited Ti/Au shows a good adhesion to the substrate with good conductive patterns. As the thickness of the deposited films increases with electroplating, the deposited films become more adhesive during soldering if soldering temperature is not too high. A major success of the process requires a high quality adhesive material between the substrate and the deposited metal films. The presented approach provides a low cost and rapid manufacturing for realizing highly integrated and lightweight wearable Microsystems. However, the printing resolutions, the residue in the apertures area, and the surface roughness of the printed filaments are major challenges towards large-scale manufacturing. The minimum aperture width in the shadow mask is 0.3 mm that also represents the width of the patterned interconnects. With proper shadow mask design, this methodology could be applicable for solder-free electronics.

The proposed approach of 3D-printed Microsystems, reported for the first time, provides highest electrical conductivity in printed electronics without curing. The integration of physical vapor deposition system with 3D printing machine is very promising for the future industry of 3D-printed Microsystems.

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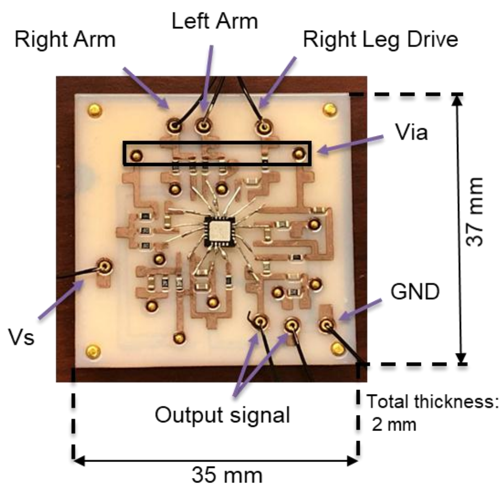

Fig 2:- The developed microsystem for ECG measurements.

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