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Modelling and characterization of electronic conductivity in 3D printed PEGDA:PEDOT polymer composites

High frequency applications

By

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Declaration

I hereby declare that, the contents and organization of this dissertation constitute my own original work and does not compromise in any way the rights of third parties, including those relating to the security of personal data.

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Abstract

Additive manufacturing is an emerging and promising technology in biomedical, automotive, avionic and electronic industries, allowing advantages in terms of cost and weight reduction and efficiency upscaling respect to traditional manufacturing. 3D printing technologies offer high degree of freedom to customize products and incorporate components such as passive circuitry elements and sensors. The availability of inexpensive, reliable, electrically conductive material is a necessary condition to fully develop the potential of 3D printing in industrial applications customizing products which incorporate electrical elements. In the electronic market to satisfy the increasing complexity of circuits layouts, while reducing the need of printed circuit board assemblies, the more efficient solution involves the incorporation of passive components in the layer-by-layer structure, which is printed during the additive manufacturing process. The idea is to print, directly through stereolithography, fundamental electronic components and sensors and furthermore to exploit the bi-material system to manufacture in the same printing process, conductive and isolating regions in up to overcome the idea of flatness in printed circuit boards (PCBs) allowing the development of a complete three-dimensional electronic. By in-process printing and the feasibility of a 3D bulk structure, vias and nets may be designed targeting non-planar electronics, by which a more compact layout geometry is obtained, enhancing the technology scaling by leading to a device miniaturization. In this way 3D printing of electronic devices in capable of enhancing the miniaturization of devices as outcome of its technology. The main focus of this Ph.D. research activity held in Materials and Micro Systems Laboratory of Politecnico di Torino (ChiLab) and in collaboration with Microla Optoelectronics S.r.l., is to model the electrical conduction mechanism in 3D printed composite material based on intrinsic conductive polymers. Several PEGDA:PEDOT resin compositions were prepared and tested with different concentration of the constituents, to evaluate through a design of experiment conductivity optimization as function of the resin formulation. The physics related to metal/polymer interface was tackled, to fabricate proper ohmic contact, while

reducing the contact resistivity. Performing DC characterizations, AC impedance and the broadband dielectric spectroscopies of multilayer 3D printed devices, a rigorous analysis methodology was established to correlate the estimated quantities to the process parameters, leading to a targeted optimization of the latter, regarding a specific application of the 3D printed device. In conclusion, both a sophisticated explanation of the electrical conduction mechanism in multilayer 3D printed PEGDA:PEDOT devices discussed through comprehensive mathematical models and a systematic methodology of impedancemetric analysis focused to the 3D printed device optimization, regarding its functionality, were accomplished. Finally, high-level experimental-numerical correlation between literature conductivity models and measures, for several 3D printed tested devices, was achieved leading to the proposition to exploit 3D printed PEGDA:PEDOT devices in different applications, such as 3D printed high frequency embedded antenna sensors or electronic traces in printed circuits for high speed signals ranging from the digital to radio-frequency domain.

This work is composed of a first section in which an introduction to intrinsic conductive polymers is described, with a direct focus on those used in a 3D printing process, while in the second the main 3D printing technologies are presented, with major focus on the Stereolithographic process. In the third section the principal models explaining the arise of conductivity in intrinsic conductive polymers are tackled, while the focus of the fourth section is on the charge transport mechanisms involved when an external electrical field is applied to the polymeric device. In the fifth chapter the measurements carried out to improve the electrical parameters of the final 3D printed device, are reported with final prototypal applications.