Micro-scale Laser-assisted Additive Manufacturing of Graphene

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Abstract

Graphene, owing to its high electrical conductivity, mechanical strength, and intrinsic flexibility, is an attractive substitute for traditional metal interconnects in flexible electronic applications. So incorporation of printed graphene features into a variety of electronic applications has become a promising research direction. Additive manufacturing (AM) is also one of the most efficient fabrication techniques for micro-scale products. The integration of a nanomaterial with unique electrical and structural properties, such as graphene, improves the properties of the layer-by-layer structure of additively manufactured products and can be considered as an evolution in micro-scale manufacturing technologies.

The present research combines the advantages of graphene and AM processes by integrating graphene in a micro-scale aerosol-jet AM process. This aerosol-jet AM technology, which is integrated in-house with a laser post-processing system, is called laser-assisted maskless micro-deposition (LAMM). Since LAMM is capable of printing inks with a wide range of viscosity (1 to 1000 cP), printing inks with higher graphene concentrations and, consequently, higher conductivity for printed interconnects is expected. Small droplet sizes (1 to 5 micron) in aerosol-jet printing also results in micro-scale features as small as 10 microns and as thin as 25 nm with defined edges. To print graphene patterns, a high-concentration graphene-based ink, compatible with the LAMM system, was developed using a chemical exfoliation process. This ink, with a graphene concentration of 3.1 mg/mL and a viscosity of 20 cP, comprises graphene flakes with lateral dimensions below 30 nm, ethyl cellulose as a stabilizer for graphene flakes, and a mixture of solvents that are compatible with the printing process. Subsequently, the injectability of graphene by LAMM has been confirmed and deposition of graphene interconnects with resistivity as low as 0.018 Ω.cm and widths ranging from 10 to 90 microns was successfully performed. These patterns, which are the finest ever printed graphene patterns, may develop miniaturized printed electronic applications of graphene [1].

To optimize the electrical properties of the printed graphene patterns, all of the excessive materials of the printed ink which are printed along with graphene, should be completely or partially decomposed. Thus, a post heat treatment process is necessary after printing. Since the main application of the printed graphene is fabrication of conductive interconnects on flexible substrates with low working temperature, low temperature or localized moving heat sources are preferable in the heat treatment processes. In this research, a laser treatment protocol is developed as a localized heat treatment process. The continuous-wave Erbium fiber laser of LAMM is used to treat the printed graphene patterns. The laser power and speed are theoretically and experimentally optimized to effectively treat the printed patterns without negatively affects the graphene flakes. The characterization results of the treated pure graphene structure are fairly comparable with the results of graphene patterns treated in a furnace. So a laser is efficiently used as a localized moving heat source to treat printed graphene patterns.

References

[1] Jabari, E., and Toyserkani, E., 2015, "Micro-Scale Aerosol-Jet Printing of Graphene Interconnects," Carbon, pp.321-329.