ELECTROTHERMAL CHARACTERIZATION OF THE ELECTRICAL RESISTANCE OF GRAPHENE CONTACTS FOR PACKAGES

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To enable the next generations of integrated circuits (ICs), characterized by three-dimensional (3D) integration and ultra-fast high-power density devices, conventional solutions appear to be inadequate. Following the International Technology Roadmap for Semiconductors, ITRS [1], innovative solutions are to be investigated, based on new packaging architectures, and on novel materials. Specifically, the performance of the electrical packages will be strongly influenced by the properties of the materials used to realize interposer layers and thermal interfaces. The interposer layer is the support of the so-called Through Package Vias (TPV), that connect the package to the integrated circuit (IC), and its electrical properties may significantly affect both the signal and power integrity [3]. The interposers must have good mechanical properties, thermal behavior, and electrical properties. Traditionally, interposers are made by silicon, but the tight requirements posed by the technology progress, in terms of frequency increase and dimensions decrease, have put on evidence major limits for such a material. Efficient heat removal is instead the first purpose for Thermal Interface Materials (TIMs), that have been traditionally filled with thermally conductive particles. This material requires a high thermal conductivity and a good thermal stability.

Due to their outstanding physical properties, graphene-based materials have been proposed as packaging material [4]. Indeed, graphene-based materials may exhibit current density of the order of 10^9 A/cm^2, Young modulus of about 1 TPa, thermal conductivity of about 3500 Wm^{-1}K^{-1}. However, all these outstanding values may dramatically drop when real world devices are fabricated, given the necessity of controlling the quality of the graphene. The high cost of such a control is among the most limiting factors for the success of such a novel material in the electronics applications. For this reason, recently the use of low-cost version of graphene is investigated, able to provide acceptable performance but dramatically lowering the fabrication cost. Recently [5], the Authors have proposed a low-cost procedure to fabricate Graphene Nanoplatelets (GNPs) and to self-assembly them into a circuit. In this paper, following the same technological procedure, we designed and realized a test-vehicle with a GNP contact, to evaluate its electrical resistance and its variation with respect to the temperature. The GNPs were obtained from commercial Expandable Graphite graphite, after thermal heating and a long mild sonication [5]. The GNPs were dispersed in isopropyl alcohol were dropped nearby the gap, under the action of an external DC field, to create the contact, see Fig.1a.

The DC electrical resistance has measured with an Agilent 34401A digital multimeter that warrants a resolution of 6.5 digit. It has been used with a four-point measurement method with the amperometric probes connected to the device terminals and the voltmetric ones inserted in close proximity of the gap. As for the temperature, it has been estimated with a type-k thermocouple connected to a data acquisition unit (Agilent 34970A).

The results reported in Fig. 1b clearly show that one of the sample exhibits the classical increase of resistance, as for conventional conductors, whereas for the other one a negative derivative of the resistance versus the temperature is observed. The possibility of having this behavior for other carbon-based materials such as carbon-nanotubes has been theoretically predicted and experimentally proven, *e.g.* [6].

Here we have found the same behavior for a contact made by GNRs: this possibility has been also predicted for a single GNR of length *l*, whose resistance may be modeled as:

$$R(T) = \frac{R_0 + R_p(T)}{M(T)} + \frac{R_0}{M(T)} \frac{l}{l_{mfp}(T)}, \tag{1}$$

where l_{mfp} is the electron mean free path, M is the number of conducting channels, $R_0 = 12.9\,\mathrm{k\Omega}$ is the *quantum resistance* and R_p is a parasitic term due to the GNR/electrode contact. The number M depends on the GNR width and chirality and is increasing with T. The resistance R_p increases with increasing T and decreases with increasing contact area. Finally, as in conventional conductors, the electron mean free path, l_{mfp}, decreases as T increases. By combining the counteracting effects of the terms in (1), it is possible to find the conditions on length, width, contact quality to obtain a resistance decreasing with T.

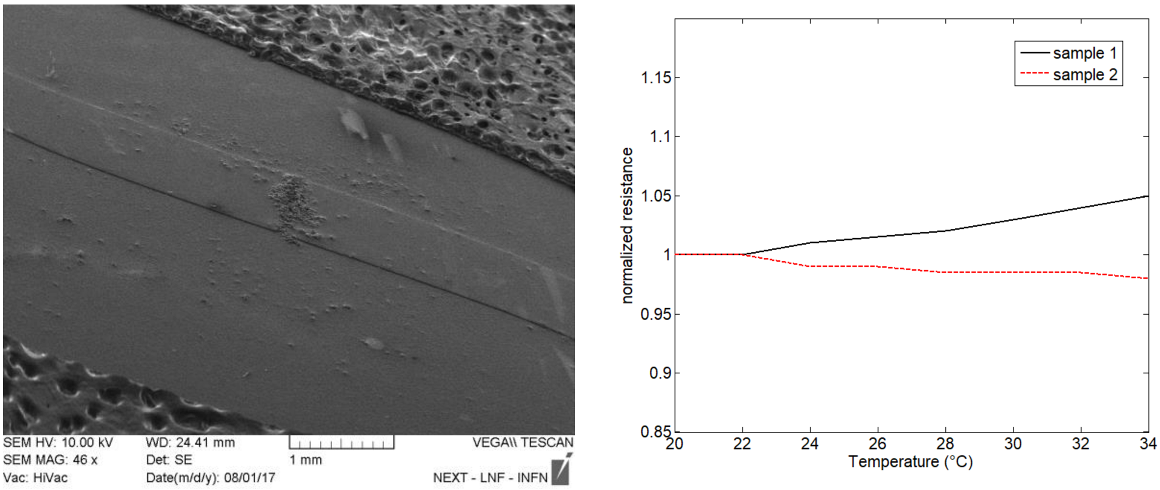

Figure 1. (a) A SEM image showing the microstrip gap filled by the GNPs; (b) Measured electrical resistance vs temperature for the two samples. The resistance is normalized to the DC value.

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