Evaluation of different conductive nanostructured particles as filler in smart piezoresistive composites

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In the last decades, piezoresistive composite materials have found extensive potential application in the fields of micro-sensors, electromechanical device, circuit breakers, touchable sensitive screen and tactile sensors for robotics, providing cheaper, accurate and faster alternatives to devices already present on the market. The properties of these materials could be tuned varying the kind and the shape of the particles, used as functional filler, and the type of matrix[1, 2].

This work presents the investigation of the piezoresistive response of composite materials based on nanostructured conductive fillers in a polydimetihylsiloxane (PDMS) insulating elastomeric matrix for tactile sensor application. Three different metal fillers were tested: the nickel and the copper powders were purchased by Vale Inco (Type 123) and Pometon (LT10) respectively, while the highly multibranched gold nanostars were synthesized with a room temperature wet synthesis[3]. These particles were chosen because of the elevate conductivity and most of all for the presence of nanosized sharp tips on their surface. Whereas PDMS was chosen as insulating matrix in order to assure a good flexibility and conformability of the final material to be capable of covering any irregular surface.

The peculiarity of these metal-polymer composites is the conduction mechanism based on quantum tunnelling phenomenon between closed particles that originates variation of electrical resistivity of several orders of magnitude. Lacking any mechanical stress, the material presents an insulating electric behavior. While upon the application of a deformation to the sample the electrical conduction drastically increases as a function of load. In fact under compression, the insulating layer between the particles is reduced causing an increase of the probability of the electrons to tunnel. Consequently the resistivity of the sample decrease exponentially. The morphology of the particles, presenting very sharp nanometric spikes on the surface, enhances this effect, because the charges injected in the composite will reside on the fillers, generating very large electric local field at the tips on the surface.

This phenomenon was observed for the first time by Bloor et al.[4] in composite prepared with nickel powder and different elastomeric matrices. We developed a similar material[5] and compared it with composites with copper and gold particles. The aim was to obtain better performances, lower process cost, thinner composite layer for integration in MEMS technology and the reduction of safety risk for the human body related to the materials used in the preparation of composite samples. In fact inhalation of nickel powder may cause cancer and sensitizing effect.

The composites were prepared dispersing the metal particles in the PDMS copolymer. The blend was gently mixed in order to not modify the electric behavior of the composite preventing the destruction of the tips on the particles surface. Then the PDMS curing agent was added to the blend and the mixture was gently mixed at room temperature. The resulting paste was outgassed for 1 hour, poured in PMMA molds with different hollow cavity shapes, realized by milling techniques and then cured in oven at 70°C for three hours. Different composites were prepared varying the copper/PDMS ratio, the copolymer/curing agent ratio and the thickness of the final samples.

All the tested composites presented a huge piezoresistive response. When a pressure from zero to 2 MPa was applied to the samples the electrical resistance showed a reduction from six to nine orders of magnitude.

The encouraging results obtained in the preliminary piezoresistive characterization demonstrate the possibility to replace the nickel materials as functional filler in piezoresistive composite material based on quantum tunneling conduction with other nanostructured particles more safe for health.

References

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Figures

Fig1. FESEM image of the nickel particles. The scale bar corresponds to 1 µm.

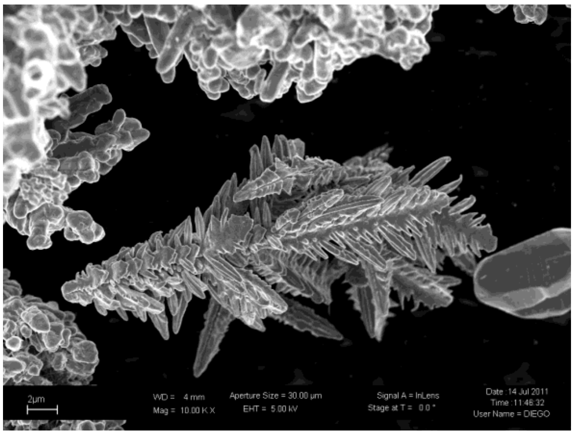

Fig1. FESEM image of the copper particles. The scale bar corresponds to 2 µm.

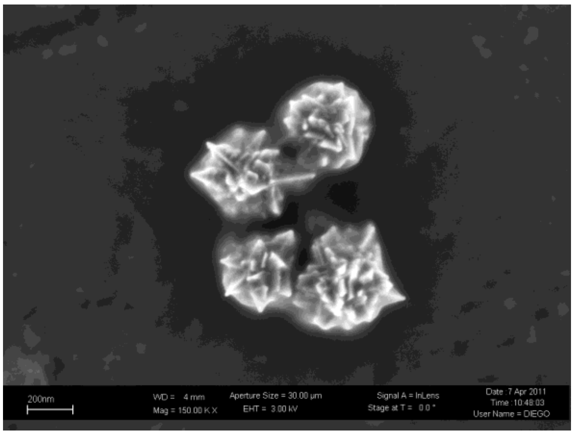

Fig3. FESEM image of the gold particles. The scale bar corresponds to 200 nm.

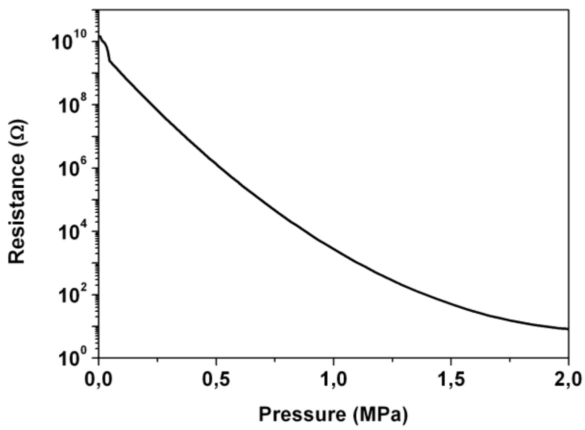

Fig4. Piezoresistive response of the composite prepared with nickel powder in PDMS matrix.