Towards very low sheet resistance of CVD graphene by $SOCl_2$ chemical doping

Giuseppe Valerio Bianco[a]
Marco Grande,[a,b] Alberto Sacchetti,[a] Pio Capezzuto,[a] and Giovanni Bruno.[a]

[a]CNR-Nanotec, [b]Politecnico di Bari; via Orabona,4 - 70124 Bari, Italy

giuseppevalerio.bianco@cnr.it

Following the discovery of the unique properties of graphene and in particular of its three core-values of transmittance, conductivity and transparency, one of the most important applications of graphene is undoubtedly in optoelectronics, where devices require transparent conductive layers (TCO). Today, the TCO material used par excellence is ITO, whose transparency (typically 85%) and sheet resistance (10-100 Ω/□) make possible the realization of devices such as LCD, PV cell, OLED and many more. However, while the transparency of a single layer graphene of about 98% is significantly higher than that of a 82–85% standard ITO, the sheet resistance of the pristine graphene layer is reported to be 0.5-1.5 KΩ/□which is much higher than that of commercialized ITO. This drawback has led the scientific community to investigate methods of doping of graphene to reduce the sheet resistance, while maintaining high transparency, in order to satisfy the demand of industrial applications. Potential doping procedures are those using HNO_3 [1], $AuCl_3$ [2,3] $FeCl_3$ [4], and Cl_2 [5]. However, only few researchers have investigated the stability aspect of doping and, in particular of doping with $AuCl_3$, as its stability is very low [4].

In this contribute, we report the study on the doping of CVD graphene, also as multilayers, using the thionyl chloride ($SOCl_2$) in a "new" treatment procedure as the dopant molecule. With this method, sheet resistance of a single layer graphene on glass significantly decreases to less than 20% without any change in transmittance. Furthermore, using a layer-by-layer doping procedure, we prepared doped-graphene multilayers and for a 6-layer graphene we obtained 12 Ω/□ at 85% transmittance, a new record for such type of structure which meets the technical target required by several industrial applications. Data are summarized in figure 1. In addition, we validated our doped-graphene layers through functional devices including heaters, microwave antennas [6], and organic solar cells [7].

References

[1] Bae S. et al.; Nat. Nanotechnol., 5 (2010) 574.
[2] Gűnes F. et al.; ACS Nano, 4 (2010) 4595
[3] Junmo Kang et al., Nano Lett., 11(2011) 5154
[4] Yi Song et al.; Nanotechnology, 25 (2014) 395701
[5] Pham VP et al.; Nanoscale, 6 (2014) 15301
[6] La Notte L., et al.; Nanoscale, 9 (2017) 62.
[7] Grande M., Bianco GV et al., Appl. Phys. Lett., 112 (2018) 251103.

Figure

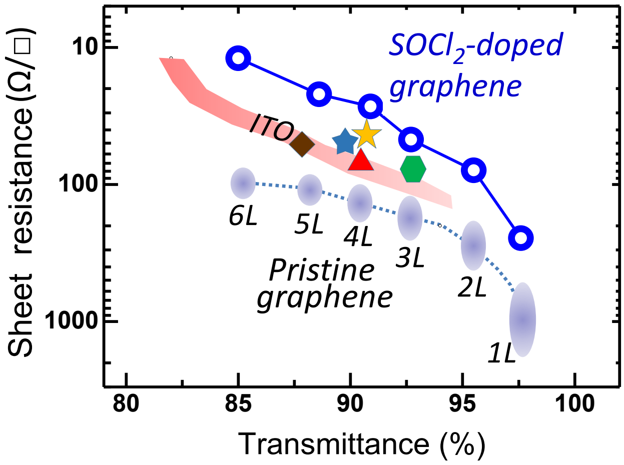

Figure 1: Sheet resistance vs Transmittance for pristine and $SOCl_2$ doped single and multilayers graphene on Corning glass. Also reported are literature data for doped-graphene layers with: HNO_3 (☆) in ref.1, $AuCl_3$ (◆) in ref.2, $AuCl_3$-CH_3NO_2 (★) in ref.3, $FeCl_3$ (▲) in ref. 4 and Cl_2-doped (⬢) in ref. 5. Also shown is the typical trend for ITO.