# Graphene combined with ultrathin metals for low cost and mechanically flexible transparent electrodes

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## Abstract

Transparent electrodes (TEs) are one of the essential elements for a wide range of optoelectronic devices and components. Indium tin oxide (ITO) is the most widely used TE since it possesses high optical transparency ($T_{opt}$) and low sheet resistance ($R_s$). However it presents several drawbacks, including fluctuating high cost due to indium scarcity, chemical instability, high temperature processing and lack of mechanical flexibility. The development of 1D or 2D nanostructured materials, such as Cu or Ag nanowires (NWs), carbon nanotubes, and graphene, has allowed the realization of ITO-free TEs. More recently roll-to-roll (R2R) and hot-pressing production of grapheme based TEs has been demonstrated, offering a good trade-off between $T_{opt}$ and $R_s$. Both R2R and hot-pressing are potentially efficient and economical, thus suitable for industrial-scale applications requiring low cost and high throughput production.

The most recent laboratory data on electrical conductivity of monolayer graphene is still far from the performance of conventional ITO or doped ZnO layers. In transferred graphene, intrinsic line defects and disruptions, as well as grain boundaries, generated residuals, can significantly influence the transport properties. In this talk, we show a hybrid TEs on flexible glass substrate consisting of hot-pressing transferred graphene onto Ag NWs mesh. We demonstrate that the combination of hot-pressing transferred graphene and Ag NWs mutually benefit these two nanomaterials. The hot-pressing method presents several advantages, including large-area fabrication, contact resistance reduction and better adhesion to the substrate thanks to the application of a conformal mechanical pressure. The result is a Ag NWs/graphene based TE with $R_s$ of about 14 Ω/sq and $T_{opt}$ of about 90%, which is an electro-optical performance comparable to commercially available ITO.

Additionally, in an effort toward direct growth of graphene, we have proposed the thermochemical vapor deposition of few layer graphene on Ni or Cu ultrathin metal films (UTMF) on glass substrates. We investigate the possibility to use UTMFs as catalysts to grow graphene, which can offer the possibility to avoid cumbersome transfer after standard growth on much thicker metal foils.