Wafer-Scale Light-weight and Flexible Graphene-Based Broadband Modulator with Ultrafast Switching Time

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Abstract

Here we report a wafer-scale light-weight and flexible broadband modulator based on Graphene/P(VDF-TrFE)/Graphene multilayer films. The P(VDF-TrFE) film not only significantly reduces the sheet resistance of graphene throughout heavy doping of ~ 0.8×10^{13} cm^{-2} by nonvolatile ferroelectric dipoles, but also acts as an efficient electro-optic (EO) layer. Such multilayer films integration with high transparency (> 90%), low sheet resistance (~ 302 Ω/□), and excellent mechanic flexibility show the potential of a flexible modulator over a broad range of wavelength. Moreover, the derived modulator exhibits strong field-induced EO modulation even under bending and one large pockels coefficient (~ 54.3 pm/V) is obtained. Such large-area modulator also demonstrates both an ultrafast switching time (< 2 μs) and outstanding environmental stability. These findings are very important for in-depth understanding of graphene and ferroelectric hybrids, enabling future explorations on next-generation high-performance, flexible transparent electronics and photonics.

References

[1] Tamagnone, M.; Fallahi, A.; Mosig, J. R.; Carrier, J. P. Nat. Photonics **8** (2014) 556-563.
[2] Bae, S. H.; Orhan, K.; Bhupendra K. S.; Kwon, J. G.; Hyoung, J. C.; Özyilmaz, B; Ahn, J. H. ACS Nano **7** (2013) 3130-3138.
[3] Ni, G. X.; Zheng, Y.; Bae, S.; Tan, C. Y.; Orhan, K.; Wu, J.; Hong, B. H.; Yao, K.; Özyilmaz, B. ACS Nano **6 (**2012) 3935-3942.
[4] Zhu, M. M.; Wu, J, Du, Z. H.; Roland Tay, Y. J.; Li, H. L.; Barbaros, O.; Edwin, Teo, H. T. Nanoscale Accepted (2015)
[5] Zhu, M. M.; Du, Z. H.; Jing, L.; Alfred Tok, I. Y.; Edwin Teo, H. T. Appl. Phys. Lett 107 (2015) 031907

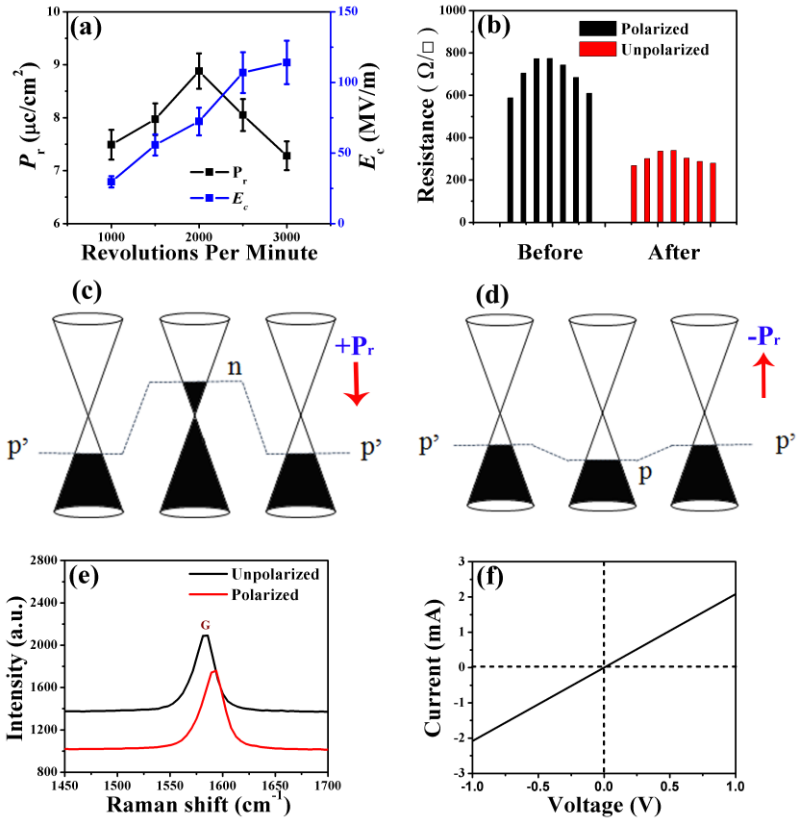

Fig. 1 (a) Remnant polarization (P_r) and coercive electric field (E_c) of P(VDF-TrFE) film as a function of spinning speed. (b) Sheet resistance of graphene film before and after polarization. Electrostatic doping in graphene with P(VDF-TrFE) film at the (c) + P_r and (d) -P_r state. After fully polarizing the ferroelectric films, the formation of p-n or p´-p´ junction in graphene can explain the change of sheet resistance. (e) Raman spectra of graphene on P(VDF-TrFE) film with and without pre-polarization. (f) *I-V* curve of wafer-scale Gr/P(VDF-TrFE) film.