Exfoliation of Black-Phosphorus in low boiling point solvents and its application in Li-ion batteries

Antonio Esau Del Rio Castillo[1], Haiyan Sun[1], Alberto Ansaldo[1], Joka Buha[2], Andrea Capasso[1], Liberato Manna[2], Vittorio Pellegrini[1], and Francesco Bonaccorso[1]

[1]Istituto Italiano di Tecnologia, Graphene Labs, Via Morego 30, Genoa, Italy
[2]Istituto Italiano di Tecnologia, Nanochemistry Department, Via Morego 30, Genoa, Italy
antonio.delrio@iit.it

Abstract

Black Phosphorus (BP) is a semiconductor layered material with a direct energy band gap [1]. The exfoliation of bulk BP to a few layers BP (FL-BP) flakes[2] allows the tuning of its (opto)electronic properties. Indeed, the energy band gap of BP changes from 0.33 eV to 1.7 eV when exfoliated from bulk to single layer[3,4]. This makes FL-BP an interesting material with potential applications in optics[5] and electronics[6,7]. Additionally, the layered structure and the chemistry of BP makes it also attractive for energy storage[8] and composite[9] applications. Recently, it was demonstrated the liquid phase exfoliation (LPE) of BP[9,10]. Unfortunately, this process is usually carried out in high boiling point (HBP) solvents[10,11], making the use of FL-BP very challenging in applications where both the toxicity and the removal of the solvent are a key, e.g., functional polymer composites[12] and printable inks[13,14].

Here, we show the LPE of BP in low boiling point (LBP) solvents, such as acetone (Fig. a), achieving material properties, i.e. lateral size (approx. 200 nm), thickness (~10 layers) and crystallinity (Fig. b), similar to the one exfoliated in HBP solvents. We used the FL-BP dispersed in acetone for the fabrication of lithium ion battery anodes. Our devices achieved a reversible specific capacity of 293 mAh g^{-1}, see Fig. c, which is higher than those obtained by BP flakes exfoliated both in high boiling point solvents (CHP, giving a specific capacity of 55 mAh g^{-1}), and water 180 mAh g^{-1} [8] (all tested at a current density of 100 mA g^{-1}). Our approach represents a step further towards the fabrication of device components based on FL-BP.

References

[1] F. Xia, et al. Nature Communications, **5** (2014) 4458.
[2] H. Liu, et al. ACS Nano, **8** (2014) 4033.
[3] V. Tran, et al. Physical Review B, **89** (2014) 235319.
[4] S. Das, et al. Nano Letters, **14** (2014) 5733.
[5] M. Buscema, et al. Nature Communications, **5** (2014) 4651.
[6] L. Li, et al,.Nature Nanotechnology, **9** (2014) 372.
[7] Y. Deng, et al. ACS Nano, **8** (2014) 8292.
[8] L. Chen, et al. Advanced Materials, **3** (2016) 510.
[9] D. Hanlon, et al. Nature Communications, **6** (2015) 8563.
[10] P. Yasaei, et al. Advanced Materials, **27** (2015) 1887.
[11] J. Kang, et al. ACS Nano, **9** (2015) 3596.
[12] S. Stankovich, et al. Nature, **442** (2006) 282.
[13] F. Torrisi, et al. ACS Nano, **6** (2012) 2992.
[14] A. Capasso, A. E. Del Rio, et al. Solid State Communications, **224** (2015) 53.

Figure

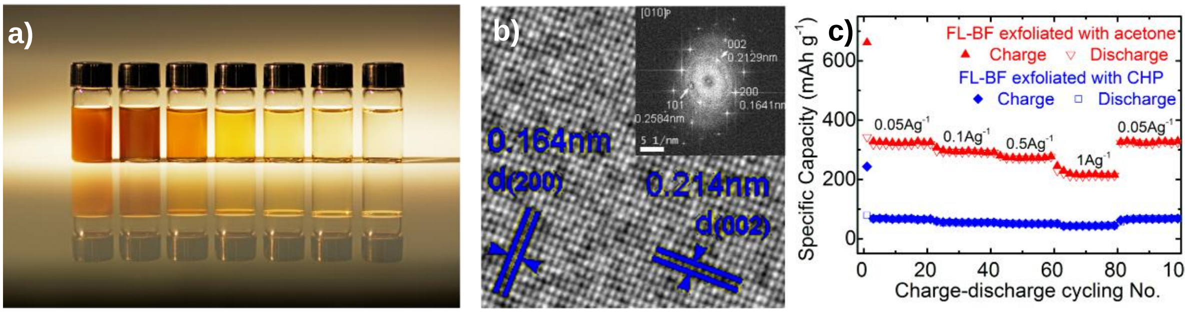

Figure 1: a) Image of FL-BP dispersion in acetone at different concentrations. b) High resolution transmission electron microscopy image of FL-BP flake; Inset: Fourier transform of the image, confirming the crystalline structure of the flake. c) Specific capacity over charge/discharge galvanostatic cycles, at different current densities, for the anode based on FL-BP in acetone (red triangles) and the one based on FL-BP in CHP (blue diamonds), at current density of 100 mA g^{-1}.