

Graphene Foams to Tune the Benefits of 2D Materials for a 3D World

M. Christian^{1*}, L. Venturi², L. Ortolani³, R. Rizzoli³, V. Palermo⁴, and V. Morandi³

¹ IMM and ISOF, CNR, Bologna, Italy, christian@bo.imm.cnr.it

² IMM, CNR and University of Bologna Department of Physics, Bologna, Italy

³ IMM, CNR, Bologna, Italy

⁴ ISOF, CNR, Bologna, Italy

Although 2D graphene has innumerable useful properties, in order to be exploited in many real world applications it must be manipulated into 3D structures. Ideally this should occur without any deterioration in electrical conductivity, to which chemically exfoliated graphene structures are prone. Instead graphene may be grown on templates of virtually any shape by Chemical Vapour Deposition (CVD), and in this way highly conductive, free-standing 3D graphene macrostructures called graphene foams (GF) were first produced from nickel foam templates in 2011 [1]. Since then there has been great interest in their use either alone or in composites with other materials in applications such as electrodes for supercapacitors [2] and Li-ion batteries [3], gas sensors [4] and adsorbents [5].

In this study, we grew GFs on metal foam templates using atmospheric pressure CVD. We were able to tune the number of graphene layers deposited and hence the robustness of the resulting foam by varying the type of template used (nickel or copper) and the flow rate of methane precursor (Figure 1). The resulting foams had a very low resistance, corresponding to excellent electrical conductivity. This is due to the fast transport channels created by the highly-branched, crystalline graphene network.

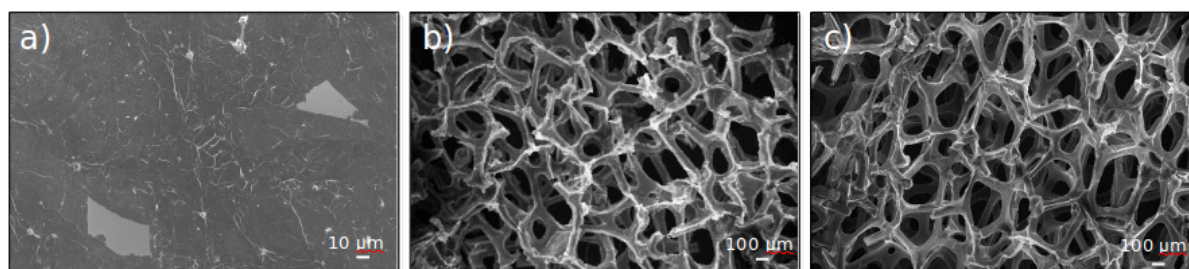


Figure 1. SEM images of (a) a collapsed GF from Cu foam template using low CH₄ flow, (b) a free-standing but fragmented GF from Cu foam template using high CH₄ flow, and (c) a robust, free-standing GF from Ni foam template using low CH₄ flow

The pore sizes of the GFs grown by this approach were on the order of around 200 μm. This is ideal for some applications (particularly biological), but many others would require a significant reduction of the pore size, for example for membranes or high density energy storage. To this end, we also synthesised 3D structures similar to GFs by CVD growth of graphene on Ni nanoparticles (<100 nm) annealed to form a network. The resulting GFs had a hierarchical structure, with both large (> 10 μm) and small (~1 μm) pores (Figure 2). These

References

- [1] Z. Chen, W. Ren et al., *Nat. Mater.* 10 (2011) 424-428
- [2] W. Deng et al., *Mater. Lett.* 137 (2014) 124-127
- [3] Y. Tang et al., *J. Power Sources* 203 (2012) 130-134
- [4] F. Yavari et al., *Sci. Rep.* 1 (2011) 166
- [5] G. Chen et al., *Appl. Surf. Sci.* 311 (2014) 808-815
- [6] We acknowledge funding by the European Union Seventh Framework Programme under Grant Agreement No. 604391 Graphene Flagship

pores could eventually be controlled by compressing the Ni particles into pellets under varying pressures.

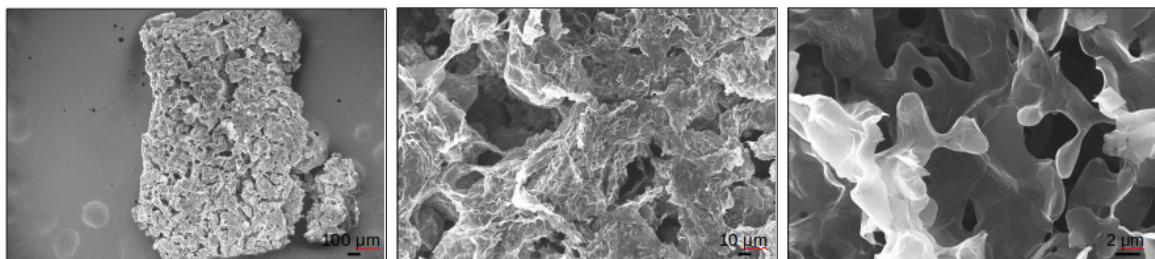


Figure 2. SEM images of GFs synthesised on Ni nanoparticles at increasing magnification, showing the range of pore sizes observed

GFs are a highly promising way to bring the outstanding properties of 2D graphene to the 3D world. They have great potential for many different applications, as they have excellent electrical conductivity as well as mechanical properties. However, so far they have been largely limited by the size of the pores in commercially available metal foams. In this study, we have suggested an approach to overcome this limitation. Future work will focus on control of the pore sizes as well as introducing further interesting properties by exploiting the different growth mechanisms of graphene on different metal nanoparticle catalysts. [6]