Molecular beam epitaxial growth of graphene on sapphire substrates at extremely high temperatures

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The discovery of graphene and its remarkable electronic properties has provided scientists and engineers with a material system for revolutionising electronics and opto-electronics. At present, the highest quality graphene is obtained by exfoliating small area (~10 μm square) flakes from graphite. Whilst the quality of graphene grown by chemical vapour deposition continues to be improved, molecular beam epitaxy is a complementary technique which offers the possibility of producing large area, high quality heterostructures with atomic level control of layer thickness, composition and doping.

Here we report the growth of graphene using a custom-designed dual chamber molecular beam epitaxy (MBE) system, based on the GENxplor from Veeco. The standard GENxplor has been specially modified by Veeco to reach growth temperatures of up to 1850^{o}C in high vacuum conditions and is capable of growth on substrates up to 3 inches in diameter. The growth chambers have a vertical configuration with the heater on top. In MBE, the substrate temperature is normally measured using an optical pyrometer. However, because we use transparent SiC and sapphire, the pyrometer measures the temperature of the substrate heater, not the substrate. Therefore, our estimate of the growth temperature is based on a thermocouple reading. In order to calibrate the temperature we have formed graphene on the Si-face of SiC by heating wafers to temperatures above 1400^{o}C. To demonstrate the scalability of the developed process, we have grown graphene on SiC substrate sizes ranging from 10x10 mm^2 up to 3-inch diameter.

We have also grown graphene layers on sapphire substrates using a SUKO-63 carbon sublimation source from Dr. Eberl MBE-Komponenten GmbH. Growth at substrate temperatures between ~1000 and ~1650^{o}C (thermocouple temperatures) have been investigated. We report the results of a wide range of techniques (reflection high energy electron diffraction (RHEED), Raman spectroscopy, X-ray photoelectron spectroscopy (XPS), atomic force microscopy, scanning tunnelling microscopy and sheet resistance measurements) that we have used to characterise these layers.