Characterization of wafer-scale CVD graphene grown on sapphire and SiC: a direct comparison

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INTRODUCTION

Graphene grown on dielectric substrates is posed to have a wide range of application, including electronics industry or as a growth template for 2D heterostructures. Among insulating substrates for graphene growth, sapphire and SiC are the most promising [1,2].

SiC is widely recognized as a substrate for the growth of high quality graphene suitable for electronics due to its excellent mobility [3]. However, the potential of sapphire, which is more affordable than SiC, is yet to be fully unveiled [4].

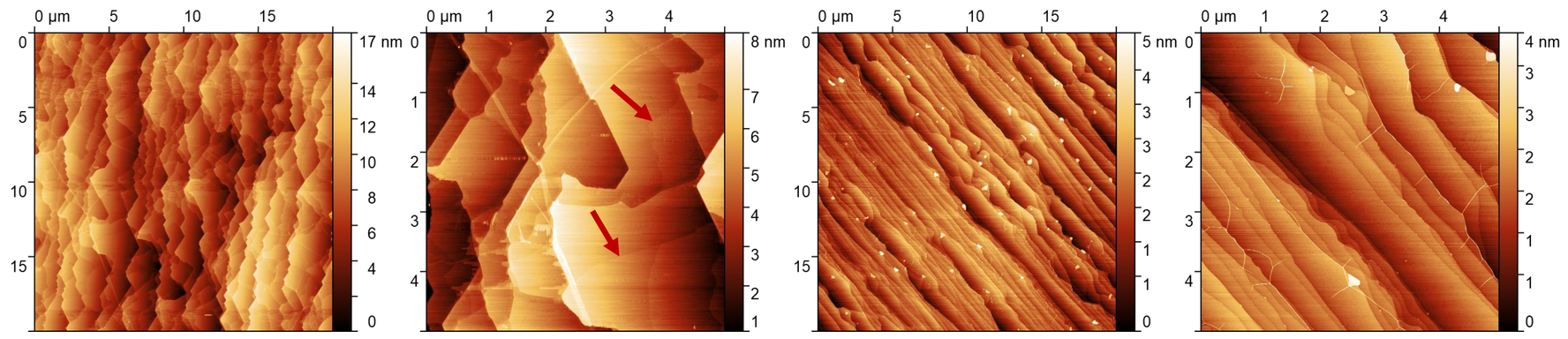
In this study, we compare (by means of AFM, Raman and Hall measurements) graphene on sapphire and SiC grown at the same process conditions. We show significant differences between substrates and suggest potential areas of applications.

RESULTS

Growth Parameters

Type of reactor	CVD CCS AIXTRON CRIUS I
Material	• Sapphire c-plane, 2-inch • 6H-SiC 10×10 mm, C- and Si-face
Pressure	700 mbar
Temperature	1560°C
Carbon source	Methane
Growth time	240 s

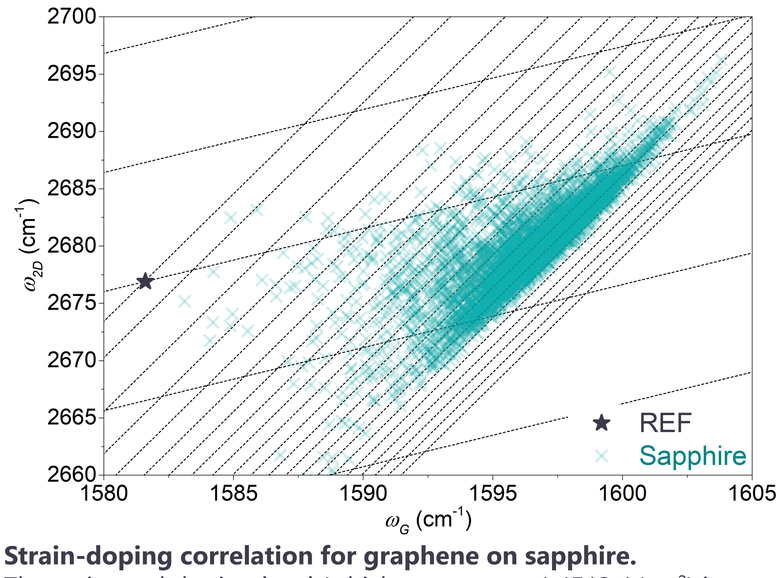
AFM



From left: graphene of sapphire, scan 20 µm; graphene on sapphire, scan 5 µm; graphene on SiC, scan 20 µm; graphene on SiC, scan 5 µm.
Graphene layer is continuous on both substrates. The atomic steps and graphene wrinkles are clearly visible on SiC and sapphire. The sapphire atomic steps are much wider than on SiC, which is favourable as it induces less strains. On sapphire, however, a considerable amount of second layer is present (red arrows). The number of wrinkles is slightly higher on SiC, indicating higher level of strain.

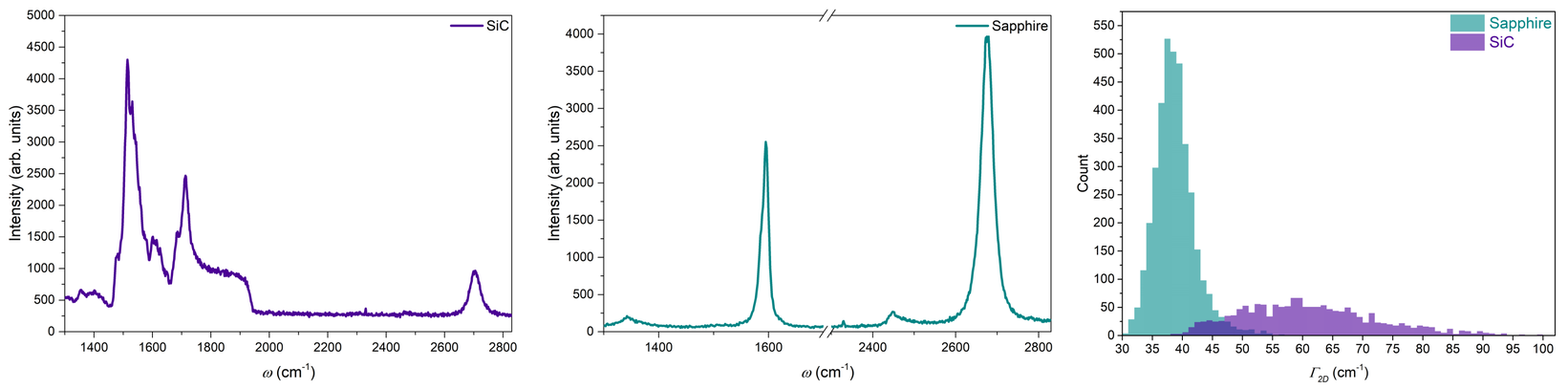
Electrical results

Property	Sapphire	SiC
Mobility [cm^2/Vs]	1200	2600 – C 590 – Si
Carrier concentration [$1/cm^2$]	1E13	2E12 – C 8E12 – Si
Sheet resistance [Ω/□]	475	1200 – C 1320 – Si

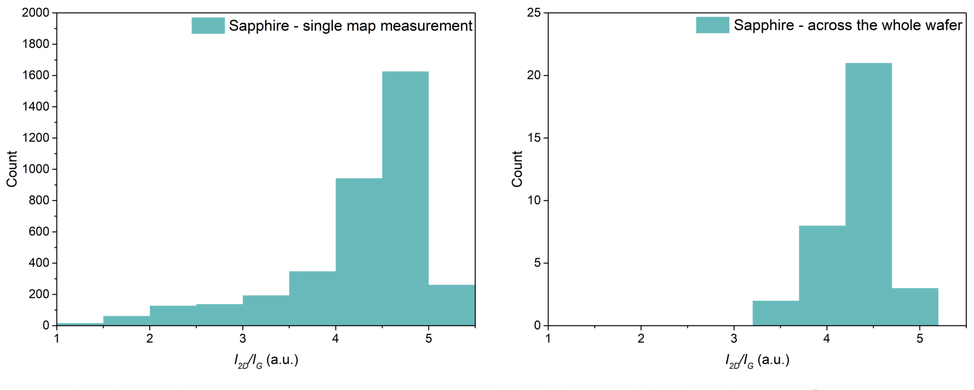


Strain-doping correlation for graphene on sapphire.
The estimated doping level (which are approx. 1.4E13 $1/cm^2$) is slightly higher than obtained in Hall measurements. Stress level is almost negligible (0 to 0.1%), which is favourable for application as a growth template.

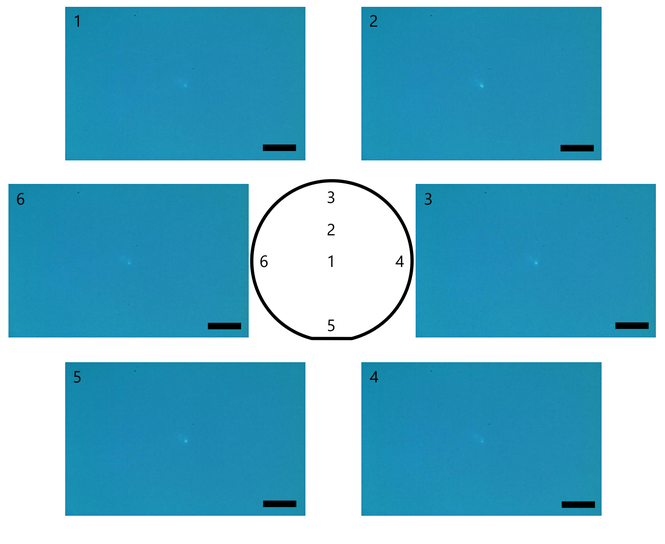
Raman characterization



Left and middle: exemplary Raman spectra of graphene on SiC and sapphire, respectively.
Right: Full width at half maximum (FWHM) of 2D peak.
A visible D peak is present in graphene on sapphire, but it is not very intensive (I_D/I_G=0.1).Since SiC peaks are at the same position as graphene G peak, it is not possible to estimate strain and doping levels. Therefore, the main quality factor is FWHM, which is significantly higher than for graphene on sapphire.



Top: I_{2D}/I_G ratio – across one scan area (10×10 µm, 1600 points, left) and across the whole wafer (36 points, right).
Right: optical uniformity across the whole 2-inch wafer. Scale bars are 10 µm.
Both Raman intensities and optical images are confirming high uniformity and quality of the graphene across the whole wafer.



CONCLUSIONS

It is possible to achieve uniform graphene monolayer on both SiC and sapphire using the same growth conditions, however, the growth needs to be performed at a very high temperature (1560°C). The are distinct differences between graphene grown on SiC and sapphire.

Graphene wrinkles are present on both substrates. AFM showed small amount of add-layer on sapphire. Raman studies indicate that graphene grown on sapphire is of much higher structural quality, with low strain levels. Electron mobility is better on SiC, but still relatively low.

Graphene on sapphire is more uniform and of higher quality than graphene on SiC, however, due to low electrical performance it is insufficient for the use in electronics industry. Nevertheless, there are other potential fields of applications, for example growth of 2D heterostructures.

THE BOTTOM LINE

Graphene grown on SiC and sapphire has relatively low electrical performance. Nonetheless, graphene on sapphire, due its uniformity and high structural quality, might be used as a growth template for 2D heterostructures.

LITERATURE

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