

Coupled electrical and heat transfer model of hBN-encapsulated graphene

Encapsulated graphene has potential as a temperature sensor. Measurement of its resistance causes Joule heating which must be characterized. The high aspect ratio poses modelling challenges.

J.V. Pearce¹, M.F. Yousafzai², I.J. Vera Marun², D. Tucker¹, P. Bramley³

1. National Physical Laboratory, Teddington, United Kingdom

2. University of Manchester, Manchester, United Kingdom

3. Metrosol Limited, Towcester, United Kingdom

Abstract

Calibration drift of temperature sensors is a well-known problem which adversely affects process control, particularly at high temperatures. New approaches are being developed e.g. [1], but degradation of resistive sensor elements is hard to prevent.

To overcome this, graphene, which has desirable electrical properties such as a relatively high, tuneable resistance, has been encapsulated in hexagonal boron nitride to protect it from oxidation. This involves nanofabrication on a silicon wafer.

Electrodes connect the graphene to external bonding pads to enable resistance measurement. This resistance measurement requires the application of a current, which causes Joule heating; this must be well understood.

A coupled electrical and thermal model is employed; the high aspect ratio (several mm across and tens of nm thick) causes some challenges with the modelling which can be overcome using domain partitioning and swept meshing.

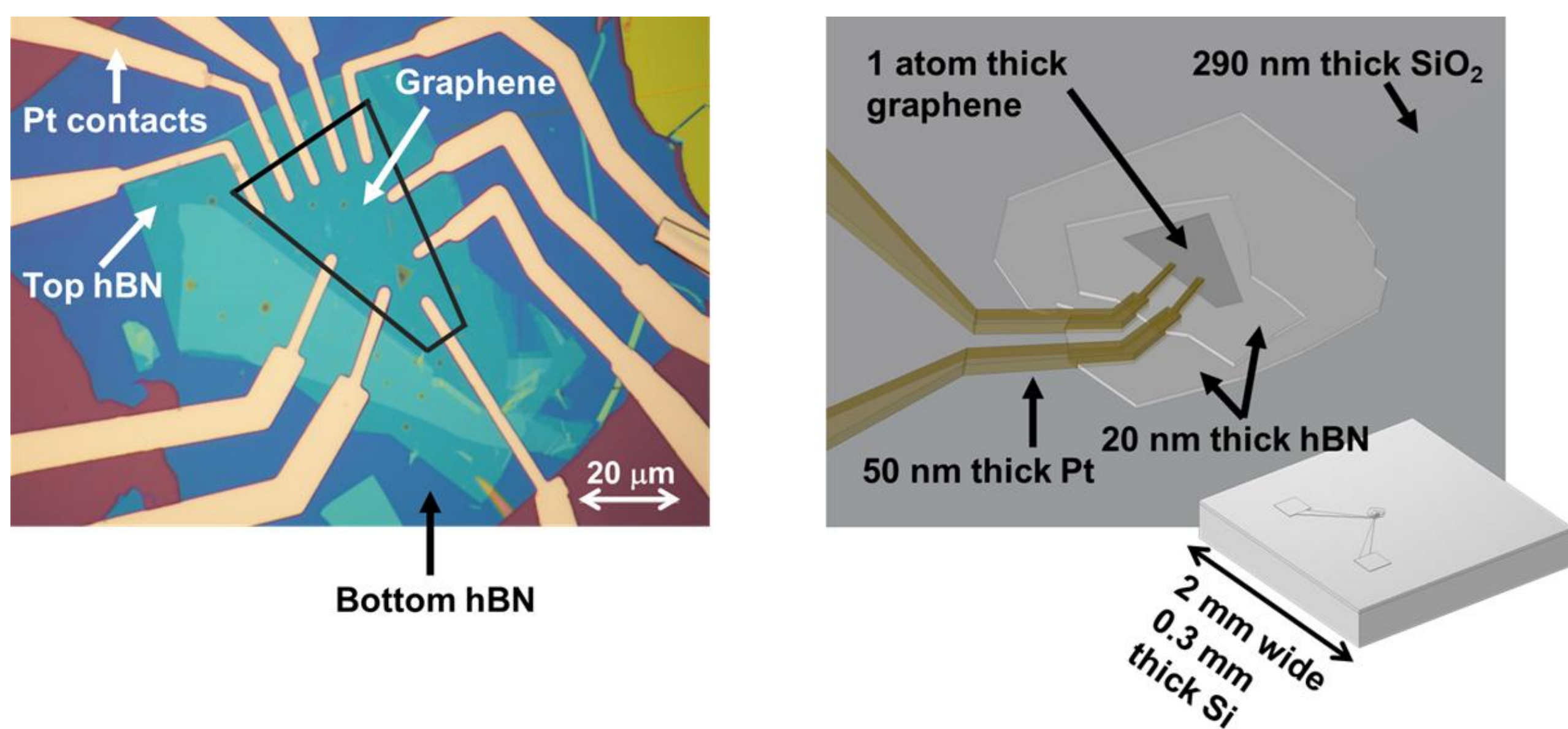


Figure 1. Geometry and dimensions of the hBN-encapsulated graphene stack. Left: optical microscope image of the real system; right: COMSOL[®] geometry. Only two electrodes are modelled, due to the complexity of the domain partitioning required for the swept mesh. The graphene is modelled as a 5 nm layer.

Methodology

Transient coupled Electric Currents and Heat Transfer in Solids interfaces are used to apply a current across the electrodes (necessary to determine the resistance). The resulting Joule heating causes a temperature rise, which is the aspect of interest here due to its influence on the thermometry.

A swept mesh is used to handle the high aspect ratio geometries, with the use of a distribution node to ensure at least two elements along the thickness. Meshing is complicated by the number of different crossovers between the layers. This can be resolved by partitioning the domains so that the geometry is more suitable for swept meshing. To manage the resulting complexity, only two of the 10 electrodes are modelled.

Results

Because a convective heat transfer boundary condition is applied on all surfaces, the temperature rise depends on the convective heat transfer coefficient. As, in use, the device will be enclosed in a protective sheath, a coefficient of $5 \text{ W m}^{-2} \text{ K}^{-1}$ is used [2], yielding a temperature rise of the entire assembly of approximately 4 mK (applied current $10 \mu\text{A}$), with a localized peak in the temperature of the graphene. The underlying Si wafer acts as a heat sink.

The model will be employed to examine both the stationary and transient 'self-heating' characteristics of the device, and the findings will be used to optimise its geometry [3]. Broadly speaking, the self-heating is comparable to that of a conventional industrial resistance thermometer.

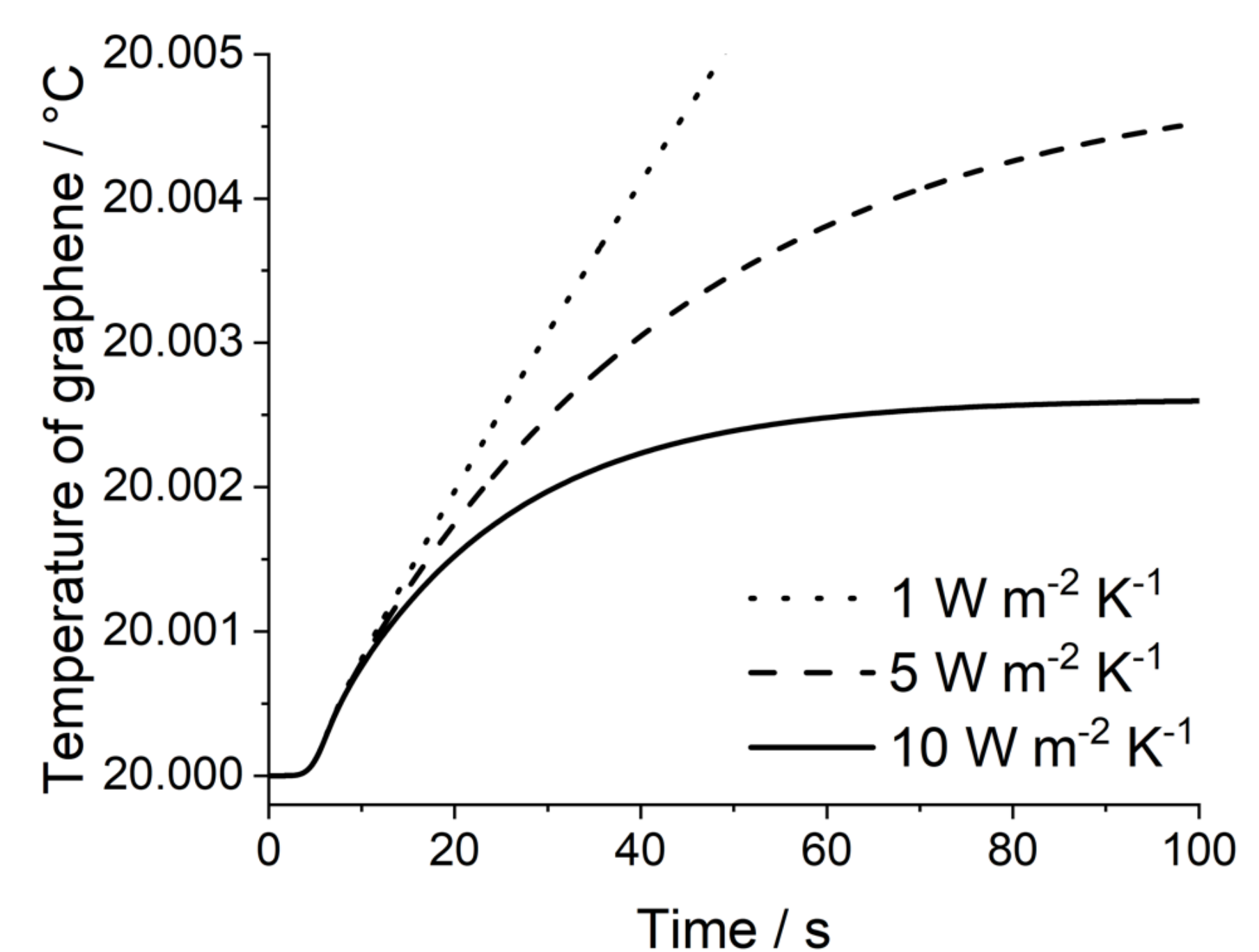


Figure 2. Temperature of the graphene as a function of time when instantaneous application of a $10 \mu\text{A}$ measuring current is made at 5 s. Representative heat transfer coefficients (typical of this kind of device) on all outer surfaces are employed.

REFERENCES

[1] www.johnson-noise-thermometer.com

[2] Values between $0.5 \text{ W m}^{-2} \text{ K}^{-1}$ and $10 \text{ W m}^{-2} \text{ K}^{-1}$ are expected.

[3] The project (23IND11 ThermoSI) has received funding from the European Partnership on Metrology, co-financed from the European Union's Horizon Europe Research and Innovation Programme and by the Participating States.

