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# Raman-based Quantitative Point Defect Density Comparison in Graphenic System

Since the isolation of the graphene from its bulk form in 2004, not only monolayer graphene but also few-layered forms, thus graphenic materials have been considered for a wide variety of applications. At the initial stage, all graphenes are extracted from bulk graphite via a mechanical exfoliation process. After a while, a chemical vapor deposition (CVD) route has been found and then large and continuous mono-to-few layer graphene has been available in recent years. Since a large number of defects in the CVD-based graphenic materials, sensitively changes the physico-chemical properties, thus the defect density must be carefully evaluated. Since most of the defect is point defect including vacancy, dopant, and topological defects, an imaging technique with sufficient atomic resolution needs to be used to identify these defects. Establishing experimental calibration, Cançado et al, proposed an equation that connects the Raman feature with ion irradiation created defect density in monolayer graphene [1]. Although exhaustive efforts have been devoted to understanding the correlation between Raman feature and defect density and layer count, a unified solution for the defect density evaluation in graphenic materials has not yet been proposed. In this context, here we propose a generalized way to quantitatively estimate the defect density in graphenic material via a non-destructive and non-contact Raman spectroscopy-based method. In this study, boron atoms substituting carbon atoms in the lattice of graphenic materials worked as point defects, and extracted boron-doped mono-to-few layered graphene has been subjected to the Raman spectroscopy investigation. Following the previous report [2], the substitutional boron atoms were introduced into bulk graphite flake using thermal diffusion of a boron atom, prior to mechanical exfoliation to obtain mono-to-few-layered graphenic materials. Detailed Raman spectroscopic analysis and collected more than 10k spectra revealed that data collected from graphenic materials that possess the same defect density form a line on the plane of $A_{2D}/A_G$–$A_{2D}/A_G$ (Fig.1). Finally, a generalized equation to calculate defect density or average inter-defect distance was proposed.

## References

[1] Cançado, L. G. et al. Nano Lett. 11 (2011), 3190–3196.
[2] Kim, Y. A. et al. ACS Nano 6 (2012), 6293–6300.

## Figures

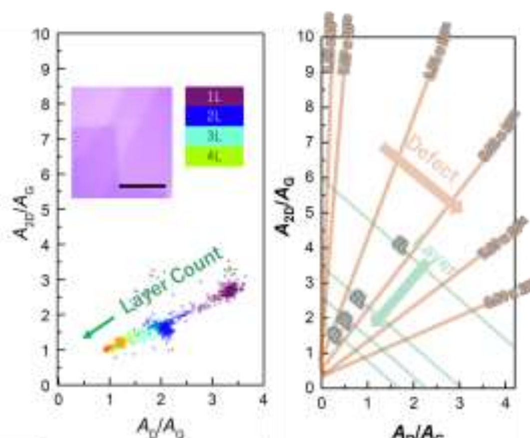


**Figure 1:** Raman data plotted on $A_{2D}/A_G$–$A_{2D}/A_G$ plane.