Optical Determination of Ice-Induced Interfacial Strain on Single-Layer Graphene

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Ice formed on a material creates a strain that is indicative of its adhesive strength with another material. Previous determinations of ice adhesion strength, a critical parameter for understanding icing physics, have proven to be highly dependent on experiment-specific conditions, such as surface roughness, icing conditions, water purity, etc. In this work, we use Raman spectroscopy to contactlessly and non-destructively measure temperature-dependent ice-induced strain for the first time. To isolate the ice-material interface, we probe the vibrational modes of single layer graphene (SLG) from 20°C to -30°C with and without ice as shown in Figure 1(a). Along with the well-known temperature-dependent Raman shift of SLG, a clear,~ 2 cm^{-1} change in the 2D-frequency (2650 cm^{-1}) developed upon ice formation is shown in Figure 1(b). We found this change in the Raman shift occurred even between supercooled water and ice at the same temperature. This small, change in the Raman shift of SLG corresponds to a 0.013% strain, which we show through spatial Raman mapping has a rich variation over the ice-SLG interface, as depicted in Figure 2. This point-by-point spatial mapping of the ice-induced strain enables precise correlation with surface roughness evaluation methods and theoretical models. Our results demonstrate that vibrational spectroscopy of 2D monolayers can precisely and locally measure strain at ice-material interfaces.

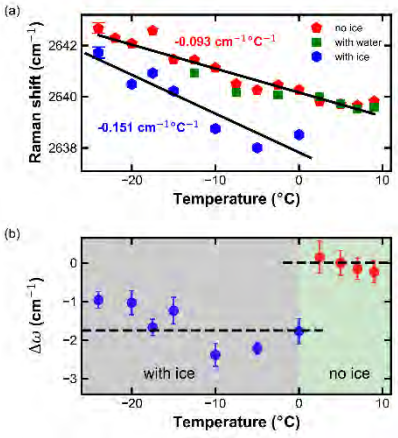

Figure 1 (a) Temperature-dependent Raman shift of the graphene 2D peak center position with no ice (red pentagons), with water (green squares) and ice (blue hexagons). (b) The difference in the 2D peak position of the graphene with and without ice, extracted from the temperature-dependent data shown in (a).

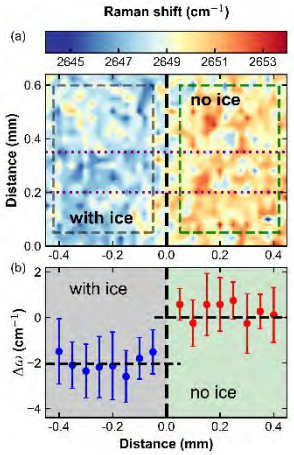

Figure 2 (a) Two-dimensional mapping of the SLG with and without ice. The figure shows the 2D peak position extracted from the fit in 50 µm steps. (b) The difference in the 2D peak position of the SLG with and without ice extracted from the two dimensional mapping shown in (a). Both Fig.1 (b) and Fig.2 (b) shows an ice-induced Raman shift difference of ∼−2cm^{-1}.

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