

# Pressure induced melting of graphene confined ice

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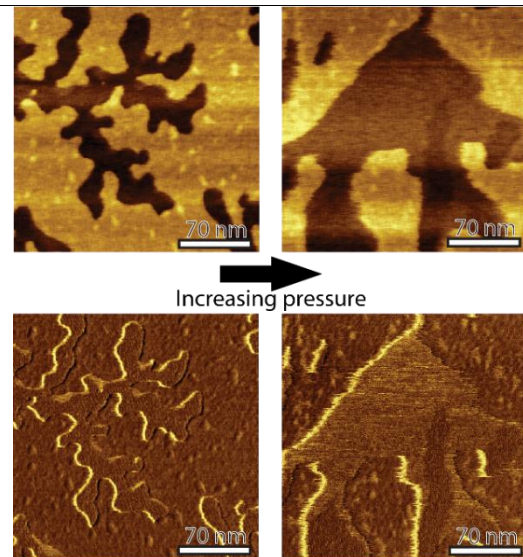
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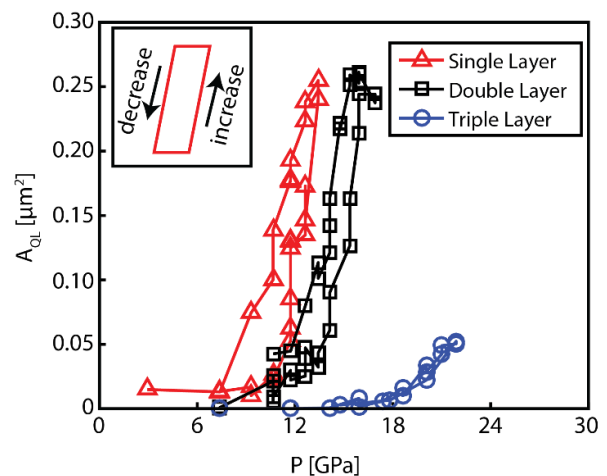
One of the anomalous thermodynamic properties of water is that its melting point decreases as the pressure increases, i.e. regelation. Since its discovery by Faraday in the 1850's, the phenomenon of pressure induced melting and freezing of water has been investigated in systems ranging from massive glaciers to Thomson's 19th century experiment of cutting a block of ice by using a thin wire. Although the latter case is often used as an example of regelation, heat and the hydrophobicity of the wire play an important role in the melting process. Here we present pressure induced melting of ice decoupled from thermal effects. The ice crystals are formed under a graphene cover which acts as a protective coating. Using an atomic force microscope (AFM), we can melt the ice by increasing the applied pressure. At high local pressures ( $\gg 1$  GPa) an order-disorder phase transition of the ice crystals takes place. The water molecules become very dynamic resulting into a quasi-liquid state. Conductive AFM maps reveal that indeed the initially polarized ice layer loses its net dipole moment, indicative of a quasi-liquid state. The situation is fully reversible, when the applied pressure is released the water molecules immediately freeze again and form a polarized ice layer. The protective graphene cover dissipates the energy induced by the scanning AFM tip away from the ice crystals. The effect of the tips' contact area and thickness of the

graphene cover have been investigated. Furthermore, the melting occurs at lower applied pressures when the system is exposed to higher temperatures.

Figures



**Figure 1:** AFM (top) and Lateral Force Images (LFM, bottom) of pressure induced melting of confined ice crystals ( $231 \times 231$  nm<sup>2</sup>). With increasing pressure the quasi-liquid state increases in area.



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**Figure 2:** Area of the quasi-liquid state ( $A_{QL}$ ) as a function of pressure ( $P$ ) for a varying amount of layers.

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