AM-FM and loss tangent imaging – two new tools for quantitative nanomechanical properties

Roger Proksch[1], Irène Revenko[1], Sophia Hohlbach[1], Jason Cleveland[1], Nick Geisse[1], Amir Moshar[1], Jason Bemis[1], Clint Callahan[1] and Mick Phillips[2]

[1]Asylum Research, 6310 Hollister Avenue, Santa Barbara, CA 93117, USA
[2] Asylum Research UK Ltd. Bicester Innovation Centre, Commerce House, Telford Road, Bicester, Oxfordshire, OX26 4LD, UK

Email: mick@asylumresearch.co.uk
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Amplitude-modulated Atomic Force Microscopy (AM-AFM), also known as tapping mode, is a proven, reliable and gentle imaging method with widespread applications. Previously, the contrast in AM-AFM has been difficult to quantify. In this work, we introduce two new techniques that allow unambiguous interpretation of material properties. AM-FM imaging combines the features and benefits of normal tapping mode with quantitative and high sensitivity of frequency modulated (FM) mode. Briefly, the topographic feedback operates in AM mode while the second resonant mode drive frequency is adjusted to keep the phase at 90 degrees, on resonance. With this approach, frequency feedback on the second resonant mode and topographic feedback on the first are decoupled, allowing much more stable, robust operation. The FM image returns a quantitative value of the frequency shift that in turn depends on the sample stiffness and can be applied to a variety of physical models. Loss tangent imaging is a recently introduced quantitative technique that recasts the interpretation of phase imaging in AM-AFM into one term that includes both the dissipated and stored energy of the tip sample interaction. Quantifying the loss tangent depends solely on the measurement of cantilever parameters at a reference position.

These two quantitative techniques can be performed simultaneously. In the example shown in Figure 1, a micro-cryotomed, cross-sectioned area of a coffee bag packaging material has been imaged. The loss tangent image on the left clearly shows the highly lossy “tie” layers connecting the low-loss metal layer with two vapor-barrier polymer layers. The AM-FM image on the right shows the relative stiffness of the five layers, with the metal layer being the stiffest and the tie layers appearing soft.

Figure 2 shows graphene deposited on a SiO2 substrate. The frequency channels shows clear contrast between the SiO2 and graphene layers, with the softer graphene layer showing a lowered resonance (roughly 500Hz lower,

out of the ~1.98MHz). The loss tangent image shows that the boundary region between the Si and graphene is dissipative.

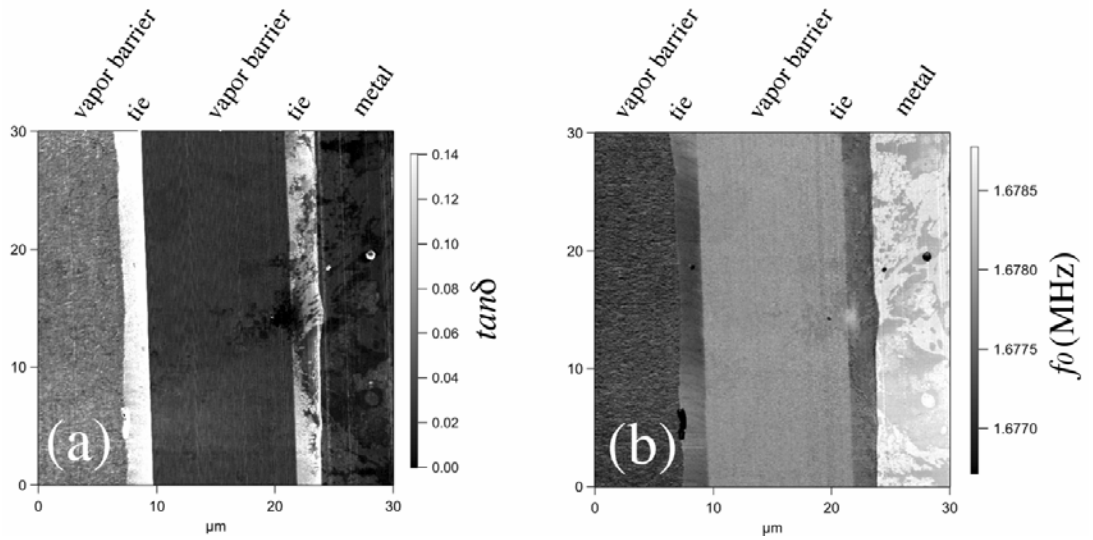

Figure 1 *(a) loss tangent and (b) AM-FM image of a cryo-microtomed packaging material. Five separate layers are visible in the 30um scan. The loss tangent image clearly shows a high loss tangent over the tie layers and the lowest over the metal layer. The AM-FM image shows the second resonance is highest over the stiff metal and lowest over the soft polymer layers.*

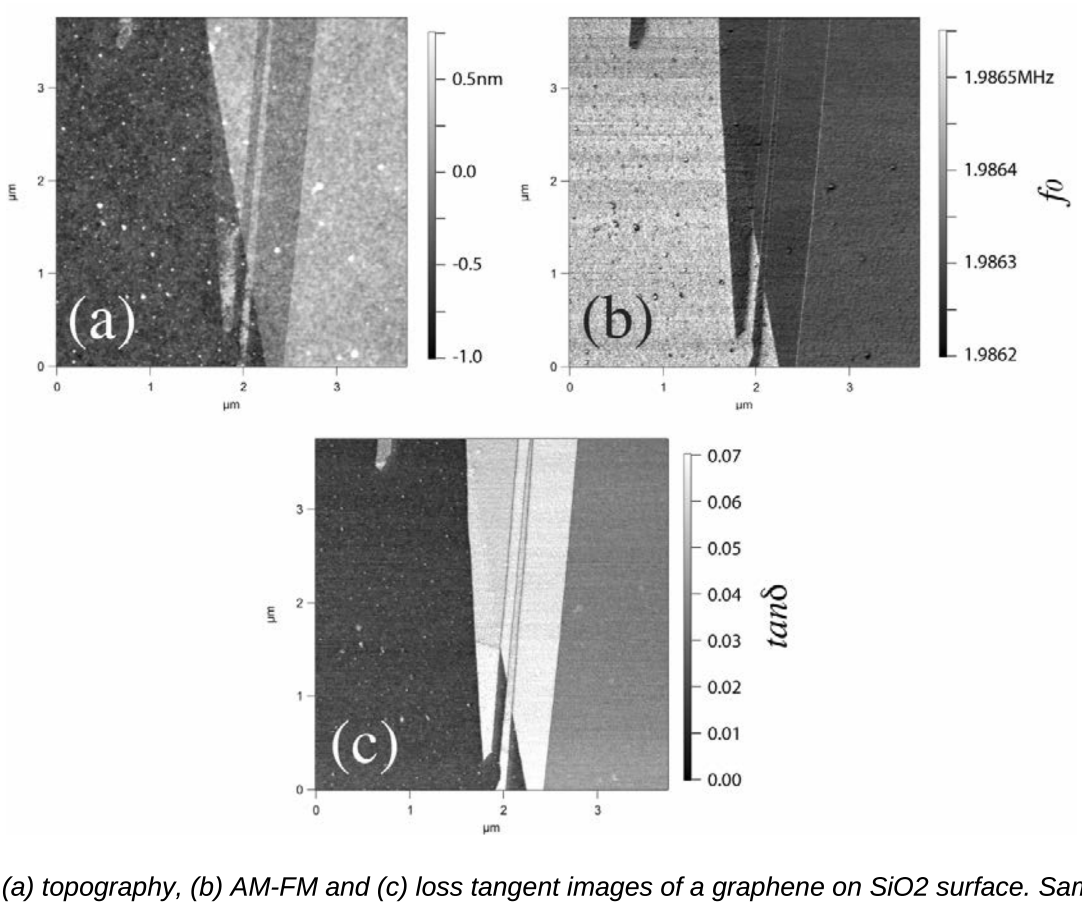

Figure 2 *(a) topography, (b) AM-FM and (c) loss tangent images of a graphene on SiO2 surface. Sample courtesy of Fereshte Ghahari, Philip Kim (Columbia) and Dan Dahlberg at University of Minnesota, USA.*