# Sensitivity of Ultrasonic and Heterodyne Force Microscopy to subsurface elastic inhomogeneities.

Oleg Kolosov

University of Oxford, Department of Materials, Parks Road, OX1 3PH, UK
(*curent address) *Symyx Technologies, 3100 Central Expressway, Santa Clara, CA 95129, USA

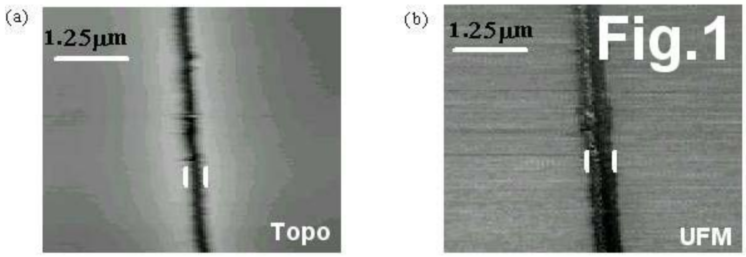
e-mail: okolosov@nano-science.com
www: www.nano-science.com

The excellent sensitivity of scanning probe microscopy (SPM) to nanoscale surface features has the coupled shortcoming – a low or no sensitivity to subsurface structures. While some SPM techniques like Scanning Thermal Microscopy (SThM) do image some subsurface structures, their resolution remains limited by the contact probe size, thermal diffusion length etc. Therefore, the ability to couple topographic probe and ultrasound (used for decades for subsurface imaging) [1] and establishing nanometer resolution ultrasonic SPM (eg Ultrasonic Force Microscopy (UFM) [2], combining MHz frequency ultrasonic excitation with the kHz frequency non-linear detection by the tip-surface contact) has high potential for nanoscale subsurface imaging.

In this paper we discuss several aspects of using UFM related techniques to detect and image subsurface elastic inhomogeneities. Such features range from individual dislocations [3], to delaminations and voids [4, 5], to mild variations of elastic moduli [6]. A key aspects of the approach – a) physical origin of the subsurface sensitivity; b) discrimination of subsurface features and surface properties (ie. adhesion, surface elasticity); c) limits of the depth sensitivity and resolution are investigated.

Interpretation of experimental data for strong inhomogeneities (complete delaminations of the oxide film from the polymer substrate in the vicinity of crack [Fig. 1]) and weak viscoelastic moduli variations (eg. polymer-metal damascene interconnect structure [Fig.2]) is given. Finally, we discuss the benefits for subsurface imaging of the phase detection of ultrasonic vibration – Heterodyne Force Microscopy (HFM) – particularly in combination with other modulation techniques like SThM and laser excitation. Author is grateful to H. Pollock and A. Hammiche for great discussions.

[1] Yasuda, K., et al. (1991). "Simultaneous measurement of surface profile and ultrasonic transmission profile by ultrasonically vibrated diamond tip." Japan J of Appl Phys, Part 1: **30**(10): 2647-8.
[2] Kolosov, O. and K. Yamanaka (1993). "Nonlinear detection of ultrasonic vibrations in an AFM." Japan J of Appl Phys, Part 2: Letters **32**(8A): L1095-L1098.
[3] Yamanaka, K., H. Ogiso and O. Kolosov, (1994). "UFM for nanometer resolution subsurface imaging." APL **64**(2): 178-80.
[4] McGuigan, A. P. et al. (2002). "Measurement of debonding in cracked nanocomposite films by UFM." APL **80**(7): 1180-1182,
[5] Diebold, A. C. (2005). "Subsurface Imaging with Scanning Ultrasound Holography." Science **310**(5745): 61-62.
[6] Cuberes, M. T. et al. (2000). "HFM of PMMA/rubber nanocomposites." J Phys D: Appl Phys **33**(19): 2347-2355.


(a)
1.25μm
Topo
(b)
1.25μm
Fig.1
UFM

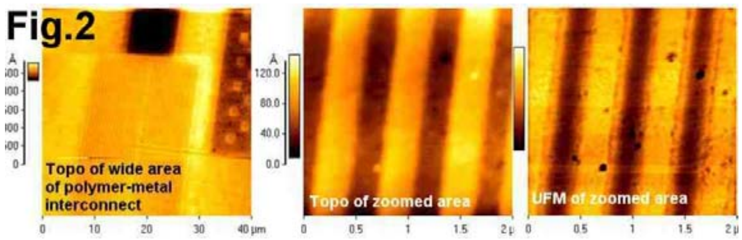


Fig.2
Å
Topo of wide area
of polymer-metal
interconnect
0
10
20
30
40 μm
Å
120.0
80.0
40.0
0.0
Topo of zoomed area
0
0.5
1
1.5
2 μ
UFM of zoomed area
0
0.5
1
1.5
2 μ