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Mapping surface elastic properties of stiff and compliant materials on the nanoscale using ultrasonic force microscopy

F. DINELLI*†, M. R. CASTELL†, D. A. RITCHIE§, N. J. MASON‡, G. A. D. BRIGGS† and O. V. KOLOSOV†

† Department of Materials, University of Oxford, Oxford OX1 3PH, UK
‡ Department of Physics, University of Oxford, Oxford, UK
§ Cavendish Laboratory, University of Cambridge, Madingley Road, Cambridge CB3 0HE, UK

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ABSTRACT

The increasing production of nano-devices and nano-composite materials has prompted the development of new instruments to probe smaller and smaller volumes. Regarding mechanical properties in particular, modified atomic force microscopes using force modulation at frequencies below the cantilever resonance have been successfully employed to investigate relatively compliant materials such as bio-materials and polymers but have shown limitations to highly stiff materials. The alternative approach of ultrasonic force microscopy (UFM) uses sample vibration at frequencies far above the cantilever primary resonance, exploiting the inertial stiffness of an atomic force microscopy cantilever and detection of ultrasonic vibration via nonlinearity of the tip–surface force interaction. In this paper we demonstrate that UFM can discriminate elastic properties of materials ranging from quite stiff to relatively compliant with a lateral resolution of a few nanometres and with high sensitivity to the elastic modulus. Furthermore a phenomenon of ultrasonically induced friction reduction permits imaging of fragile samples otherwise swept away in conventional contact mode atomic force microscopes. The possible influence of adhesive properties also has been analysed and criteria for distinguishing elastic and adhesive contributions have been established. We also explore another promising application of UFM for detection of nanoscale subsurface delamination.

§ 1. INTRODUCTION

In the last few decades, there has been a big effort to miniaturize electronic devices and produce nano-composite materials, ranging from semiconductor devices, like quantum structures, and to composites, such as fibres embedded in an epoxy matrix, and polymer blends. All of this has prompted the development of new instruments to probe small volumes and evaluate the desired physical quantities with submicron lateral and depth resolutions. Regarding mechanical properties in particular, instruments developed in the past to measure bulk properties are gradually becoming insufficient for this purpose. Research then moved in the direction of

* Present address: University of Washington, Benson Hall, PO Box 351750, Seattle, WA, 98195, USA; e-mail: fdinelli@u.washington.edu.

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