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Material sensitive scanning probe microscopy of subsurface semiconductor nanostructures via beam exit Ar ion polishing

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Abstract
Whereas scanning probe microscopy (SPM) is highly appreciated for its nanometre scale resolution and sensitivity to surface properties, it generally cannot image solid state nanostructures under the immediate sample surface. Existing methods of cross-sectioning (focused ion beam milling and mechanical and Ar ion polishing) are either prohibitively slow or cannot provide a required surface quality. In this paper we present a novel method of Ar ion beam cross-section polishing via a beam exiting the sample. In this approach, a sample is tilted at a small angle with respect to the polishing beam that enters from underneath the surface of interest and exits at a glancing angle. This creates an almost perfect nanometre scale flat cross-section with close to open angle prismatic shape of the polished and pristine sample surfaces ideal for SPM imaging. Using the new method and material sensitive ultrasonic force microscopy we mapped the internal structure of an InSb/InAs quantum dot superlattice of 18 nm layer periodicity with the depth resolution of the order of 5 nm. We also report using this method to reveal details of interfaces in VLSI (very large scale of integration) low *k* dielectric interconnects, as well as discussing the performance of the new approach for SPM as well as for scanning electron microscopy studies of nanostructured materials and devices.

(Some figures in this article are in colour only in the electronic version)

1. Background and introduction

Scanning probe microscopy (SPM) with its superb nanometre scale resolution and ultimate sensitivity to surface properties is an indispensable tool for modern nanotechnology and development of novel semiconductor devices. At the same time, due to the very nature of proximity probe imaging, SPM cannot be directly applied to imaging of nanostructures that are located under the immediate sample surface, even though in many cases (e.g. for quantum dots and quantum well structures, buried interfaces, multilayer interconnects, to mention a few) the most intriguing features for the researcher are under the surface of the device. A possible solution would be to cross-section the sample and to expose underlying structures to nanoscale probing. A traditional mechanical sectioning and polishing (commonly used for e.g. device packaging studies) [1] creates extensive microscale damage, as well as surface roughness, and results in contamination by abrasive particles, rendering its unsuitable for SPM applications. A niche technique of cross-sectional scanning tunnelling microscopy (X-STM) works well for crystalline samples, producing high quality imaging of features in the cleavage plane [2], but, unfortunately, it is not suitable for non-crystalline materials, and even for crystalline materials, sample preparation in the X-STM to a great degree remains an act of art.

Perhaps, the most promising methods for SPM applications would be ion polishing techniques where subsurface structures are exposed by ion milling—namely focused ion beam, or FIB, milling [3] and Ar ion cross-section polishing [4]. FIB uses narrow (down to 10 nm diameter) beam of