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The Helium Ion Microscope for Interconnect Material Imaging

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1. Abstract

The recently developed helium ion microscope (HIM) can be operated in three imaging modes; ion induced secondary electron (SE) mode, Rutherford Backscatter imaging (RBI) mode, and scanning transmission ion imaging (STIM) mode. When low k dielectric or copper interconnects are imaged in these modes, it was found that unique pattern dimension and fidelity information at sub-nanometer resolution is available for the first time. Our paper will discuss the helium ion microscope architecture and the imaging modes that may make it a tool of particular value to the low-k dielectric and dual damascene copper interconnect technologies.

2. Introduction

Imaging of fine line features patterned in low-k (k<2.5) materials is important for Cu/low-k interconnect validation of the dry etch, wet clean, and ashing back end process steps. Conventional SEM imaging of low-k materials often results in changes to the low-k material line width, edge roughness, and shape. This makes SEM interpretation of the real shape difficult. Additionally, at the low accelerating voltages required to image low-k materials in an SEM, contrast is poor and pattern transfer fidelity is subsequently hard to qualify.

In our paper, we investigate the ability of the HIM to provide low-k dielectric images that contain pattern information not available with an SEM. The helium ion interaction with low-k materials was also investigated. During this investigation, a potential new application, the imaging of the underlying copper through the interlevel dielectric, was explored as well.

3. Helium ion microscopy (HIM) fundamentals

A detailed explanation of the HIM has been presented in earlier literature [(1)]. In summary, the current family of HIM is capable of 0.29 nm SE mode image resolution on certain samples, as is seen in figure 1.

The mean of the HIM induced secondary electron (SE) energy distribution is peaked around 2 eV[(2)]. In conducting samples, the mean free path of a 2 eV electron is generally around 1nm. This short mean free path is the reason for the extreme surface sensitivity of the HIM induced SE images. This low SE energy also means that the surfaces of low Z materials, such as low-k materials, carbon nanotubes and the contaminant organic films in interconnect materials are readily visible in HIM SE mode.

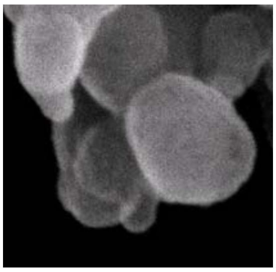
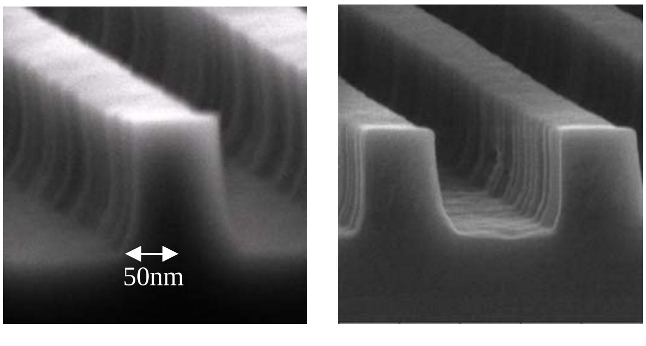


Figure 1: A helium ion microscope SE image of graphitized carbon nodules at 1.14 million times magnification and a resolution of 0.29 nm in a 100 nm field of view.

Also because of the low secondary electron launch energy, the secondary electron yields, and hence image gray levels, are easily modulated by resistance, capacitance or doping concentration variations of any interconnects being imaged. This has important implications for failure analysis applications and when determining interconnect type and integrity during the BEOL process steps.

4a. Experiments and Results: Low-k imaging

A 100 nm thick low-k film (SiCOH, k=2.4, porosity: 21%), was CVD deposited onto a SiCN/SiO_2 film on a silicon wafer. The low-k film was capped with a 60 nm CVD dense Low-k (k=3.1) cap. The low-k stack was then trench etched through a photoresist mask followed by He/H_2 ashing to form patterned lines and spaces of 140 nm pitch. The line/space samples were viewed at various imaging angles in HIM SE mode.



Figures 2a and b: Helium ion microscope SE images of low-k dielectric lines and spaces in a 500nm “Birdseye” field of view at different ion dosages without the aid of line averaging or sample coating. These images were taken at 35 keV and 0. 2 pA.

Figures 2 a and b show “Birdseye” HIM views of the low–k material line and space patterns. Varying image doses were used to acquire a wide range of images and although some material modification was observed at higher image dosages, pattern line widths and edge roughness information could generally be obtained. It should be noted that the SiCOH, the low-k dielectric being used, does charge in an SEM and must be observed at low keV in order to prevent charging. From Casino[3] simulations, the range of a 1 keV electron in this low-k material is about 70 nm’s. However, from SRIM[4], calculations, the range of the 40 keV helium ions used is nearly 700nm’s. Although the helium beam energy is higher, the combination of the lower helium ion beam current and the longer range of the ions means that the power density to the dielectric is nearly a factor of 10 lower with the 40 keV helium ion beam than it is with a 1 keV electron beam. From this interpretation, one might therefore expect the dielectric to shrink less and be less damaged during ion imaging than during SEM imaging. This seems to be the case[8].

4b. Experiments and Results: Through Dielectric Imaging of Buried Interconnects

It was noted that the CMP copper (M1) underlying 130 nm’s of low-k dielectric was observable in SE mode, even through the overlying dielectric. Figures 3a and b show a side view drawing of the copper and its overlying dielectric (left), and an SE mode image of CMP copper wiring (M1) beneath 130nm’s of low-k dielectric (right). This “through dielectric” imaging has SEM analogs in high voltage SEM work and in SEM images apparently modulated by capacitive voltage coupling (CCVC) effects[5]. There have been several theories proposed [6,7,8] why this effect is evident in an SE image of a helium ion microscope. These theories all depend on the low energy of the electrons launched in the sample by the incident ion beam.

The ion range in this particular low-k dielectric is greater than 500 nm’s at an ion energy of 35 keV. The ions pass completely through the dielectric and enter into the copper. Upon interacting with the copper surface, low energy secondary electrons are emitted that may have a long range mean free path in the low-k material that is sufficient for them to escape back through the dielectric to be collected by the secondary electron detector. This theory is supported by the copper grain contrast variation seen in figure 3b.

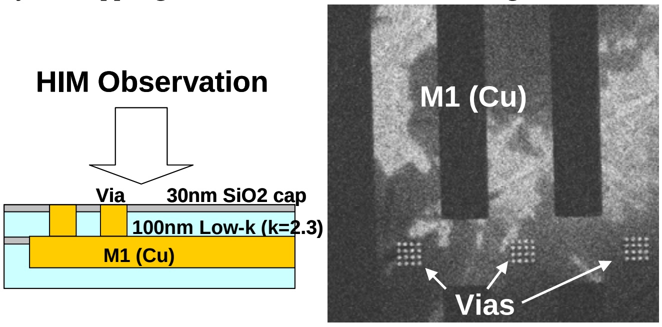


Figure 3a: Side view drawing of copper wiring and its overlying dielectric (left). Figure 3b: CMP power plane seen in HIM SE mode through 130 nm of low-k dielectric material (right). HIM SE imaging conditions were 25 keV and 2 pA and a 20 μm field of view.

This contrast results from secondary electron yields at the copper surface being lower for copper grains with axes close to the ion beam axis. For those copper grains with axes’ orientations oblique to the ion beam axis, the ion/copper atom interaction is near the copper surface and the secondary electron flux launched back into the dielectric is high. Thus, these grains might appear more white than the well aligned grains.

5. Discussion

The helium ion microscope (HIM) is capable of imaging in secondary electron mode. For rapid assessment of the fidelity of pattern transfer in low-k materials without the need of TEM sample preparation, the HIM has proved to be useful. With the proper image orientation, the surface topography of low-k materials can be viewed while much of the beam energy that could alter the dielectric’s mechanical properties is deposited deep into the underlying subsurface material. In order to fully qualify the microscope on a wider range of materials and imaging configurations, further application work is required. More HIM SE mode as well as back scattered ion mode and scanning transmission ion mode material imaging evaluations are recommended.

6. Summary

The value of helium ion microscope SE images in assessing the quality of patterned low-k and of subsurface interconnect materials has been reviewed. A comparison of the helium ion microscope’s SE images with those from an SEM seems to imply that the helium ion microscope can provide information not available from an SEM image. Although some material modification during imaging was observed, the ion induced signal-to-damage ratio seemed to be better in the helium ion microscope than in an SEM.

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