A Quantitative Probe Current Distribution Characterization Technique for Focused Ion Beam

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Focused Ion Beam (FIB) technology continues to scale into the nano regime to keep pace with the scaling of semiconductor processes and biological science research. As the requirements for higher image resolution and machining precision increase, the necessity for comprehensive analysis of ion beam profile is becoming increasingly important and more challenging.

Characterizing the probe size and complete current profile of ion beams is complex due to the non-Gaussian current distribution common in most beams. Traditionally, an ion beam is evaluated for its figure of merit based on an image collected on a hetero-interface sample (e.g. Au on C sample), scanning the beam across a knife edge, or performing a spot and line burns onto a sample.[1] Edge resolution analysis is the most common technique used to characterize the FWHM of the ion beam (sometimes referred to as probe size), but the accuracy is limited due to inherent sputtering of the edge and poor signal-to-noise ratio at low beam currents. Line and spot burn / resist exposure techniques do provide a direct measurement of the beam, but are prone to environmental and analysis errors (e.g. uneven sputtering due to grain boundaries and material redeposition). Additionally, such techniques only capture the center Gaussian portion of the beam and do not quantitatively capture the full beam profile (e.g. beam broadening at the base and tail region of the probe).

For failure analysis and circuit edit nanomachining applications, it is particularly important to measure beam tails since the tail region negatively impact the machining precision of the vias, particularly when invoking enhancing gas chemistry due to higher etch enhancement for the lower current density parts of the beam. The most direct technique for measuring the ion beam current distribution profile is through the measurement of ion trajectory and interaction volume in a crystalline substrate.[2] For very small probe sizes (sub 5nm regime) applying such techniques is essential to accurately quantifying the beam current distribution.

In this paper, an empirical technique for analyzing the ion beam current distribution profile is discussed. In the experiment, a wide range of doses are delivered into a crystalline semiconductor substrate in a series of single pixel lines. The ion implantation sites are lifted out by a dual-beam and analyzed under a transmission electron microscope (TEM) (Fig. 1). At the lowest dose, no subsurface damages are detected by TEM (Fig. 1a). At a higher dose (Fig. 1b), the center region of the ion beam (where the current density is highest) starts to disrupt the crystalline lattice and amorphize the substrate. As higher doses are applied, the amorphous region continues to grow laterally as the outer part of the probe current also reaches the damage threshold. Eventually, for high enough doses, surface sputtering begins (Fig. 1g).

The evolution of the outline of these amorphous regions correlates with the ion beam current distribution. In a simple approach, the ion beam current distribution can be derived by de-convoluting the dimension of the measured damage profile with a TRIM simulated point spread function (PSF) of the subsurface damages. In a more comprehensive approach, the ion beam current distribution profile is assumed to be a sum of Gaussian (or other) distributions with free parameters. The simulated damage profile is obtained by convolution of this beam representation and the TRIM PSF. Ion beam current distribution profile is derived from the best fit between the simulated damage profile and empirical damage profile by adjusting the distribution parameters (Fig. 2).

The principals behind this technique will be discussed and modeling and empirical results of a gallium beam profile are presented in this paper. This method will be applied in optimizing gallium column designs and in studying novel ion sources like lithium magneto optical trapped ionization source (MOTIS), helium and neon gas field ionization sources (GFIS).

Reference

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2. G. Ben Assayag, C. Vieu1, J. Gierak, P. Sudraud, and A. Corbin, J. Vac. Sci. Technol. B **11**, 2420 (1993).

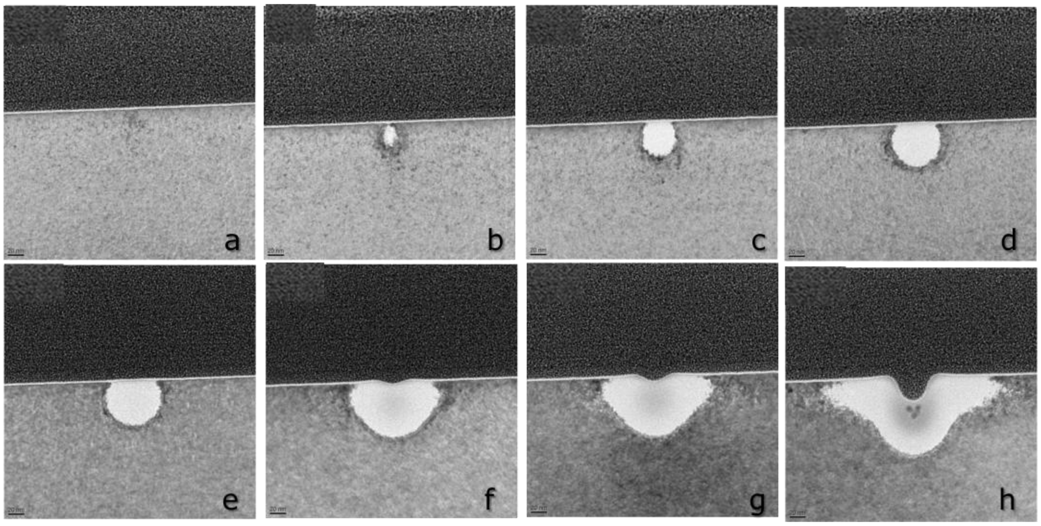

Figure 1: TEM damage evolution micrographs of a 30 keV Gallium beam. Ion doses increase from (a) to (h).

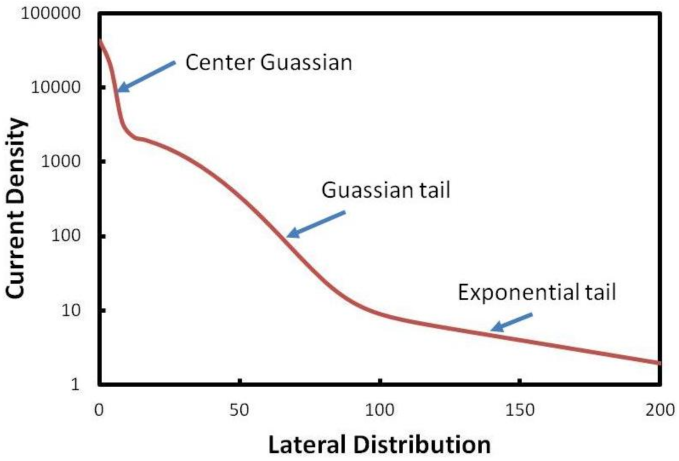

Figure 2: An example beam current density profile shown in logarithmic scale.