Ion-solid interactions studied with a cold-atom rubidium FIB

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Focused Ion Beams are important tools for the semiconductor industry. Essential applications are editing circuits and repairing masks in the development phase, and failure analysis during wafer processing. Following Moore's law, FIBs also face higher demands in terms of pattern size and reduced damage, which may require alternative sources to replace the ubiquitous Ga LMIS.

Here a FIB instrument that may overcome these limitations is presented. The essential innovation is the use of a cold-atom ion source[1] based on photoionization of a laser-intensified and cooled atomic rubidium beam. The whole source is mounted on a commercial FIB column and first ion microscopy and milling experiments have been performed (Figure 1).

Compared to a Ga FIB, similar brightness but lower energy spread can be achieved. Ion-optical simulations predict that a probe resolution of order 1 nm is possible for currents of a few picoamperes at 8 keV beam energy.[2]

Milling patterns were produced on pure Si substrates. For each Rb ion, ~1.5 Si atoms are sputtered during milling at 8 keV experimentally, compared to 1.7 atoms/ion in SRIM[3] simulations. SRIM predicts that Rb has a slightly higher sputter yield than Ga (see Figure 2).

The current focus of the research is to optimize the system performance and to study ion-sample interactions such as secondary emission and sputtering yield involving typical material used in the semiconductor industry including SiO_2, GaAs, Pt, Cu, etc. Future work will investigate staining of various samples by Rb implantation.

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[1] J. J. McClelland, A. V. Steele, B. Knuffman, K. A. Twedt, A. Schwarzkopf, and T. M. Wilson, Phys. Rev. Appl. **3**, 011302 (2016).

[2] G. T. Haaf, S. H. W. Wouters, D. F. J. Nijhof, P. H. A. Mutsaers, and E. J. D. Vredenbregt, Ultramicroscopy **190**, 12-20 (2018).

[3] J. Ziegler, J. Biersack, and M. Ziegler, See www.srim.org for calculation description and software download.

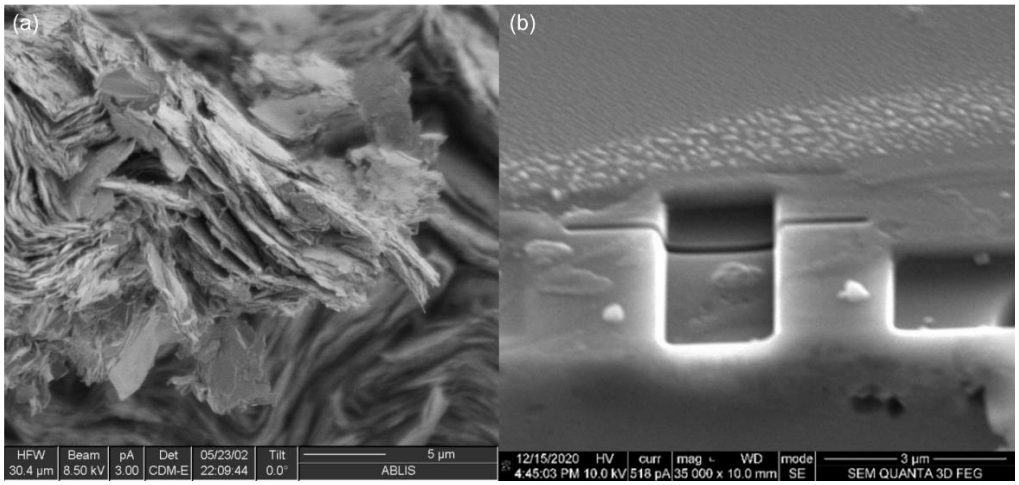

Figure 1: Imaging and milling experiments taken by our Rb FIB: (a) A secondary electron image of a pencil lead sample by Rb ions. The image is acquired under 8.5 keV working voltage and 2 pA beam current. The resolution of the image is around 30 nm. (b) The image shows a box pattern milled by Rb^+ ions under 8.5 keV, with a burn line by Ga^+ to illustrate the milling depth.

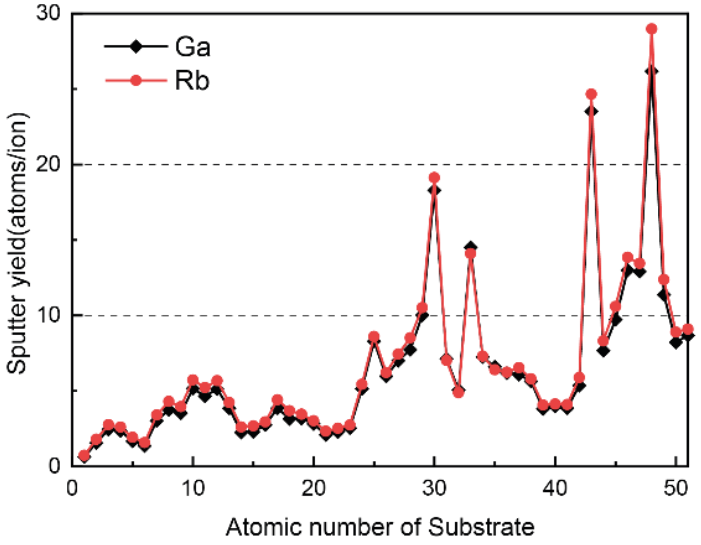

Figure 2: Sputter yield simulation by SRIM: This figure plots two curves of Ga^+ (in black) and Rb^+ (in red) predicting the milling ability over various substrate. The energy of ions is set to 10 keV, and each simulation applies 10000 ions in total. The result shows our Rb^+ performs a better ability on sputter yield than Ga^+.