Focused ion beam milling monitored by an additional electrode

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We present an idea to control the progress during focused ion beam milling of cantilevers. Since the monitoring options given by the focused ion beam machine did not satisfy our needs for complete control of the milling process, we decided to measure the current behind the target. A simple current to voltage converter and the electric setup are presented in this Note. © *2006 American Institute of Physics.* [DOI: 10.1063/1.2336759]

The idea of focused ion beam milling for cantilever modification has been described in various publications.[1–3] Mostly the goal was to improve the properties of commercially available cantilevers. We used ion beam milling to design cantilevers that would allow a tip oscillation parallel to the surface. The modifications involved a complete cut across the entire cantilever. Although the beam current may be measured while milling, it was difficult to exactly determine when the eroded line goes all the way through the bombarded material. Some unsuccessful trials revealed that the cantilevers were not perfectly cut all the way along the eroded line pattern [see Fig. 1(a)]. The present Note describes an idea and its realization to improve the *in situ* monitoring of the milling process. More specifically, the ion current onto a conducting surface behind the eroded target has been measured. The onset of this current marks the moment when the ion beam goes through the target. Plotting this signal as a function of the position of the ion beam (given by the voltage on the beam deflection plates) allows us to monitor the effectiveness of the cutting process for any position along the cutting pattern. This, of course, requires the current measuring device to exhibit a fast enough response to allow a direct measurement with the repetition rate of the digital beam raster. The experiments have been performed using a commercial liquid metal ion gun from Ionoptika (LMIG IOG25) in a homebuilt chamber. A beam of 25 keV Ga ions has been used, the spot size was around 2 μm in diameter, leading to a target current of 0.7 nA.

A two stage current to voltage converter has been applied to measure the current (see Fig. 2). On the input side we use a 560 $k\Omega$ resistor and two diodes to protect the input against excessive currents and voltages, e.g., from a charged sample. A 1 MΩ resistor combined with a 1/100 voltage divider is used instead of a 100 MΩ resistor not only for the convenience of commercial availability but also because of the stability. For the presented application the increased thermal noise due to this scheme is of minor importance. The 10 pF capacity above the 1 MΩ resistor serves as a low pass filter defining the bandwidth and preventing the system from oscillating. The second stage allows offset adjustment and boosts the signal again. The overall gain of the amplifier is 1 V/nA. The bandwidth was determined to be 5 kHz.

To apply the technique, a special sample mounting technique is used. As the details may vary for every application, only a short sketch of the idea will be presented rather than the complete drawing (see Fig. 3). The latter can be obtained by mail if needed. The whole sample mount including the cantilever is electrically connected. The current to the sample is measured and can be used to adjust the focus. Between the sample mount and the cantilever we glued a glass plate for isolation (blue). On top of that a 50 μm thick stainless steel foil was glued (red). We used Epotek 27D, but any other UHV compatible epoxy should work. The current onto the stainless steel foil was measured using the described current to voltage converter (IVC). Now the progress while milling can be monitored as a function of the beam position. While we used a simple oscilloscope, one could easily use a personal computer (PC) to monitor and store the results. Figure 1 shows two cantilevers: For the one shown in (a) we milled before our improvement, one can see the region where the ion beam did not go all the way down. The one in (b) is perfectly milled due to the monitoring we performed using the setup mentioned above.

The described technique can also be used to acquire current images of the sample. Figure 4(a) shows such an image using the cantilever itself as an electrode. As light gray represents high current, one can easily identify the shape of the cantilever. The dark u-shaped lines are the milled parts of the cantilever, where the ion beam gets through the cantilever hitting the backplate and hence not contributing to the current image. Figure 4(b) shows a more detailed view of the milled lines. The inverted image (c) is acquired using the same field of view, but using the backplate behind the cantilever as electrode. Here the lines where the structure is milled into the cantilever appear bright. One can even detect

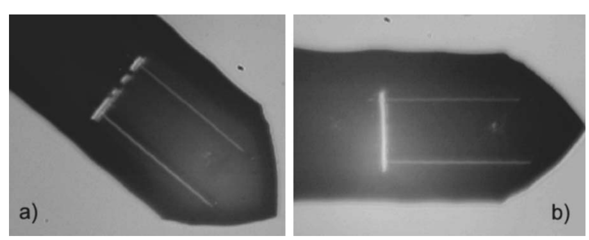

FIG. 1. Micrographs of cantilevers milled without (a) and with (b) the monitoring system; the images (a) and (b) were acquired with an optical microscope using backlight illumination

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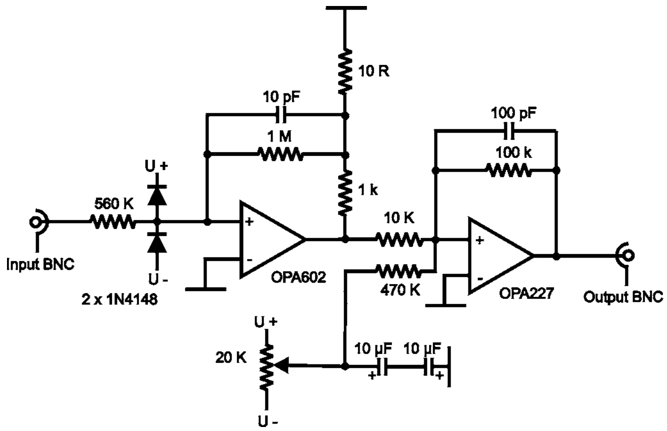

FIG. 2. Circuit diagram of the current to voltage converter (IVC), the 560 kΩ resistor, and the two diodes protecting the input against excessive current and voltage. The potentiometer allows us to adjust the offset.

some features which may appear due to details of the milling process. The corners of the u-shaped structure appear brighter: as we first cut the two long lines and then the short one finishing that shape, we increased the time the ion beam hits the cantilever in those corners; this leads to a slightly larger structure in the corners. The cross section in (d) clearly shows that right below the corner, the lower of the long lines appears slightly darker. This is a result of milling the short line after the other lines as this deposits eroded material around the line, eventually filling up the previously milled line.

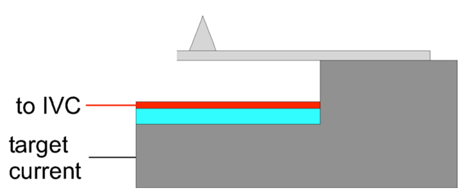

FIG. 3. (Color online) Schematic drawing of the sample mount with the cantilever, an insulating glass plate (marked blue), and a metal sheet (marked red); the target current is measured on the sample mount, while the current traversing the target is drawn from the metal sheet.

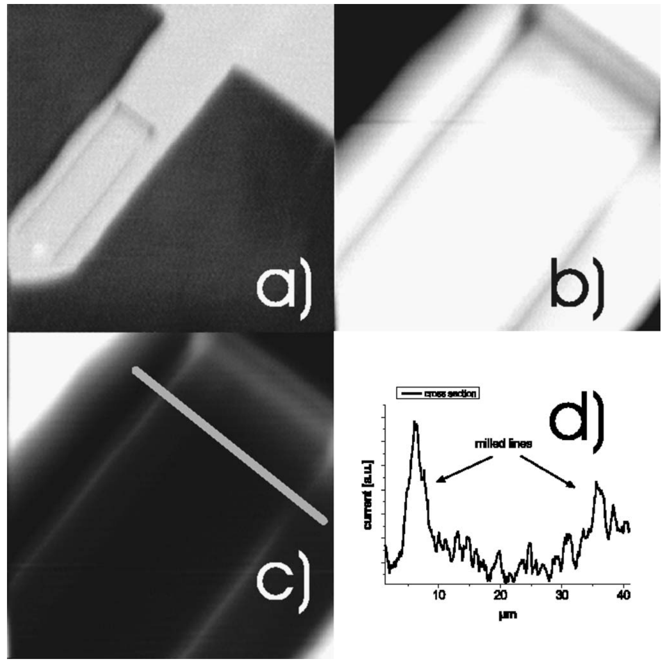

FIG. 4. (a) shows a current image taken using a IVC at the cantilever. The field of view is $275 \times 275\ \mu\text{m}^2$. (b) shows a zoom to $60 \times 60\ \mu\text{m}^2$ (bright indicates high current). (c) shows the inverted signal of (b) acquired by measuring the current behind the cantilever, the milled through structures are visible. The field of view again is $60 \times 60\ \mu\text{m}^2$. (d) shows a cross section along the line in (c) where one can identify a lower current on the right hand side, indicating that material has been redeposited.

We showed that with minimal technical effort it is possible to improve the milling capabilities of the focused ion beam machine.

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