Microfabricated resistive high sensitivity nanoprobe for scanning thermal microscopy

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In modern micro- and nanoelectronics technology, investigation and control of thermal effects in micro- and nanostructures is already a crucial issue. What is even more important, the investigation has to be performed with nanometer resolution, enabling recognition of details smaller than 50 nm.

Since the invention of STM, the probe has been the crucial part of scanning probe microscopes of all kinds. Scanning thermal microscopy measurements started from equipping the device with a thermoresistive probe to measure temperature, as described by Dinwiddie and Pylkki in 1994 [2]. First commercially available thermal probes were made of Wollaston wire, which consists of platinum core and silver coating, which diameters are 5 µm and 75 µm, correspondingly. For its good endurance, the probe is very useful in microelectronics diagnostics, but because it is the bent wire to image the surface, the thermally active area is few micrometers large, which does not allow for reliable quantitative investigations in nanoscale. On the other hand cantilevers with Platinum based nanowires, whose tip radius was of 30 nm [3], could only be fabricated singly, which made their laboratory applications difficult.

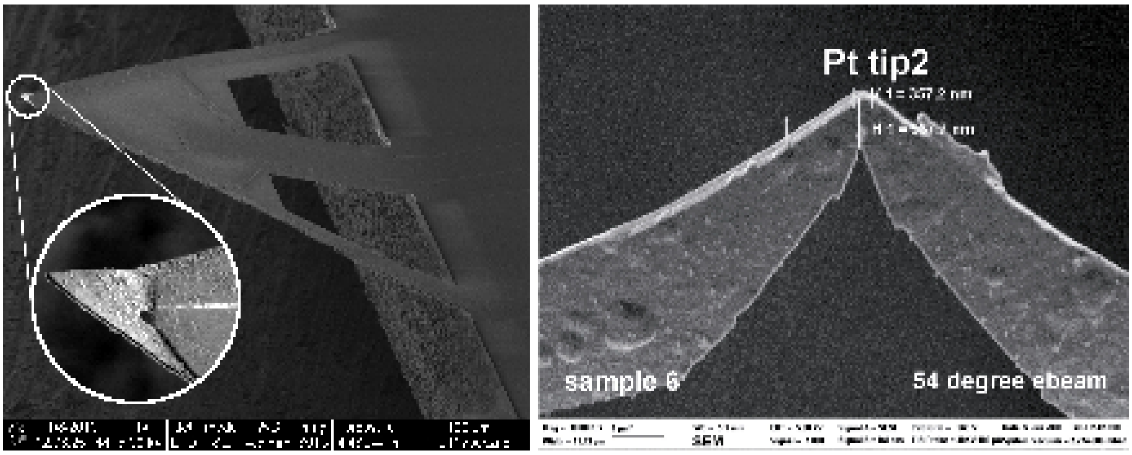
In this paper fabrication process and applications of novel micromachined AFM microcantilevers with conductive platinum tips acting as thermal sensors are presented. The cantilever beam with an integrated metal tip and connecting lines was Batch fabricated using an innovative double-sided micromachining technique, including a front side KOH etch of the tip, combined with backside etching of a silicon membrane. Batch lithography/etch patterning process combined with focused ion beam (FIB) modification allows to manufacture thermally active, resistive tips with radius of curvature in the range of 80 nm.

The main advantage of the developed technology is the tip fabrication sequence. Combination of batch processing of the initial shape of the tip and subsequent FIB post-processing facilitates manufacturing sharp, 3D tips with radius of curvature below 100 nm, which considerably improves spatial resolution of the probe (Fig. 1). Such a freestanding platinum tip-resistor suspended in the air significantly reduces the thermal mass of the thermally active area increasing thermal resolution and reducing thermal response time. Moreover, the cantilever body is made of thermally low-conductive silicon nitride which ensures the best thermal insulation between the thermal tip and sensor supporting body. In addition we deposited a wide metal path on the beam to increase reflectivity of illumination needed for the detection of the cantilever deflection and avoid heating of the thermal probe by the microscope laser.

In addition, in order to ensure the best measurement performance the fabricated probe has four contacts integrated, which enables the resistive tip to be connected to either 2-point or 4-point measurement set-up. The four-point method of measuring the resistance allows for increased accuracy of measurements changes in resistance of the tip as a function of temperature without being influenced by resistance changes in sensor connections.

In our experiments we used a developed high precision AC measurement system, which contained selective amplifiers and precise signal generators. It enables not only for temperature measurements but also for power dissipation in the investigated structure. Results of temperature calibration procedure (Fig. 2) and of temperature distribution measurements are presented (Fig. 3). The calibration was performed using a dedicated reference stage, which included a Pt100 thermoresistive sensor. The determined resolution of temperature measurement is 50 mK in the bandwidth of 100 Hz. For temperature distribution measurements a polycrystalline silicon microfuse was used as a sample. The obtained results confirm the measurement parameters enabling imaging of thermal details smaller than 50 nm.

References
[1] G. Binnig, et. Al, Phys. Rev. Lett. 1986 56(9) 930-933
[2] R.B. Dinwiddie, et. al, Thermal Conductivity 22, Technomics, Lancaster PA, 1994, pp. 668-677.
[3] K. Edinger et al., J. Vac. Sci. Technol., B 19 (6), 2856, (2001)



(a) (b)

Figure 1. Scanning electron microscopy images of fabricated nanoprobe: (a) the cantilever and tip before FIB processing, (b) the tip after FIB cutting.

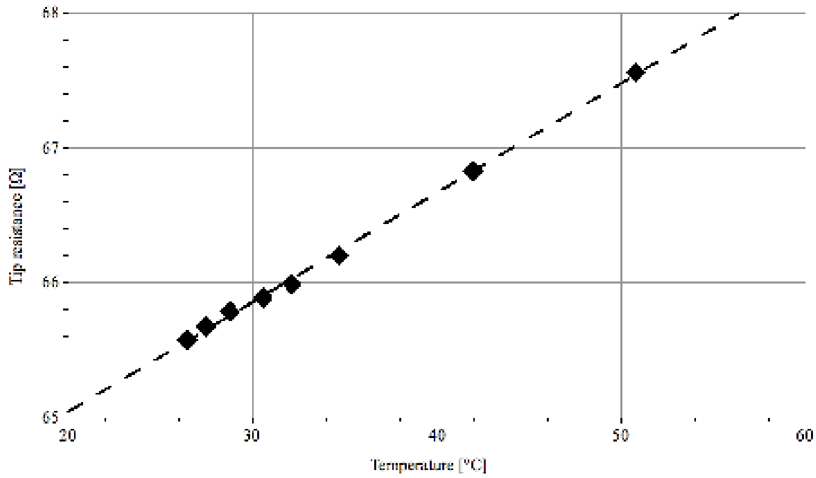
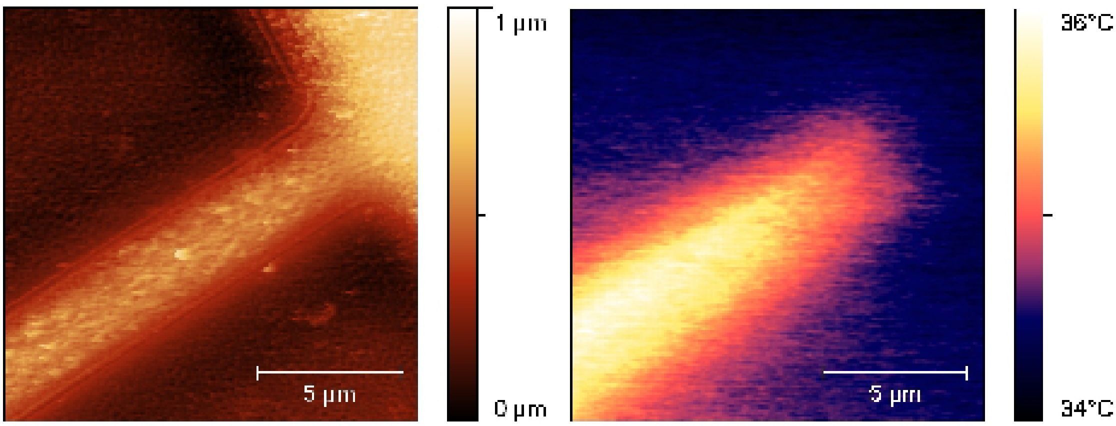


Figure 2. Calibration of thermal sensitivity of a cantilever that was not processed by FIB. The regression line reveals sensitivity of 0.08 Ω/K. Temperature reference was taken from a Pt100 measurement.



(a) (b)

Figure 3. Result of simultaneous measurement of (a) topography and (b) temperature of a polycrystalline silicon microfuse. Current of 4 mA was applied to the fuse contacts. In the topography image small grains of silicon dioxide (diameter of about 200 nm) can be seen, which proves the desired spatial resolution of the designed nanoprobe.