High Speed AFM Imaging and Nanolithography with Parallel Scanning Probes

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A crucial limitation of Scanning Probe Microscopy (SPM) and Scanning Probe Lithography (SPL) is the size of the measurement area and the speed with which this area can be imaged or patterned. The array-systems of an autonomous working cantilever have the capability to significantly increase the measurement area and speed compared to single cantilevers [1]. As previously presented, the productivity of this kind of imaging and metrology systems can be increased due to massively parallel scanning probes with a very large scale of integration. In the frame of the PRONANO-Project, we built an array of 128 cantilevers having a pitch of 200µm, which resulted in huge data acquisition processing to form the composite image using a DSP controlling unit for every cantilever [2]. This paper presents the fabrication and characterization of an active parallel cantilever device integrating four self-sensing and self-actuating probes in an array controlled by a multi-channel FPGA controller. The cantilevers are actuated thermo-mechanically and their bending is measured piezoresistively [3]. The piezoresistive read-out routinely ensures atomic resolution and a high imaging speed [4, 5]. The thermo-mechanical actuation allows a static and dynamic actuation of every cantilever individually and enables a simultaneous AFM operation of all cantilevers in an array [6]. The static actuation has a hub of +/- 1.6µm and the dynamic actuation is used to drive the cantilever at his resonance frequency. The active cantilever array is moved over a surface to be imaged by a piezoelectric, nano-positioning scanner, which enables 200µm x 200µm scanning with 0.2nm resolution. The pitch between cantilever tips is 125µm and allows in case of parallel imaging with one scan of the stage to acquire an image with a maximum size of 0.5 mm x 0.2 mm. The integrated cantilever devices are fabricated from a silicon-on-insulator (SOI) wafer using surface micromachining and a gas chopping plasma-etching process [6]. The SPL technology is based on the use of low-energy electrons for direct writing or mask-less lithography [7]. The electron emission current is in the range of 1 to 50 pA and undergoes Fowler-Nordheim (FN) law [4].Every cantilever has an 8µm-high conical silicon tip [8], which is used as an AFM scanning probe and as an electron field emitter. The radius of the tip is smaller than 20nm and capable of emitting electrons at 30 to 60 Volts. The multichannel, scalable controller architecture allows four FPGA boards to scan and collect data simultaneously. The scanning time of 4096 x 1024 px frame is 10:40 mins, the pixel resolution is 122 nm, and the required memory is 128 Mbits, assuming 32 bits topography data for 1 pixel. The communication channel must be capable to transfer the data stream in real time. The data transfer system based on 1GBit Ethernet was designed allowing a packet of 64 pixels to be transmitted for less than 10µs, which exceed the required throughput in the case mentioned above. This throughput of the parallel set-up is more than 6 orders of magnitude larger than SPM working with a single cantilever. In this paper, we will present investigation on throughput, reproducibility, resolution, positioning accuracy in case of AFM Imaging and FN-Nanolithography.

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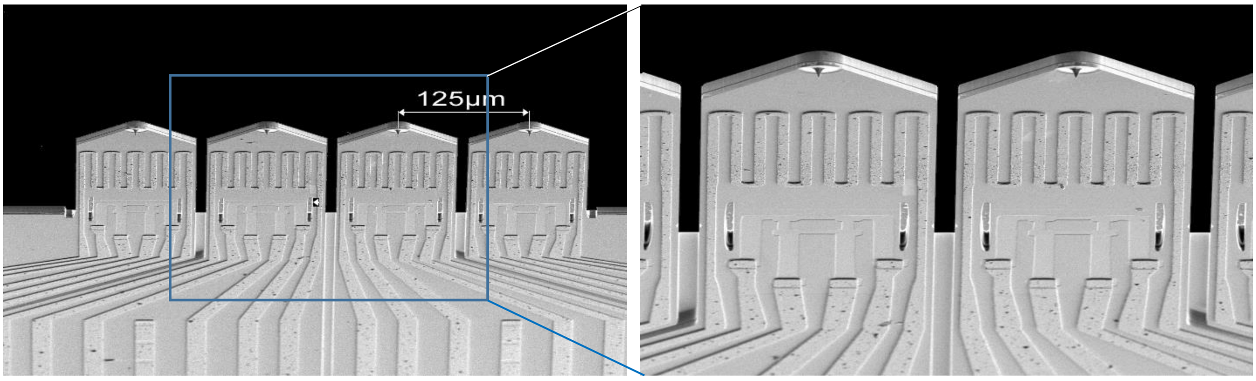

Figure 1. “Quattro” cantilever array based on self-sensing and self-transduced cantilever.

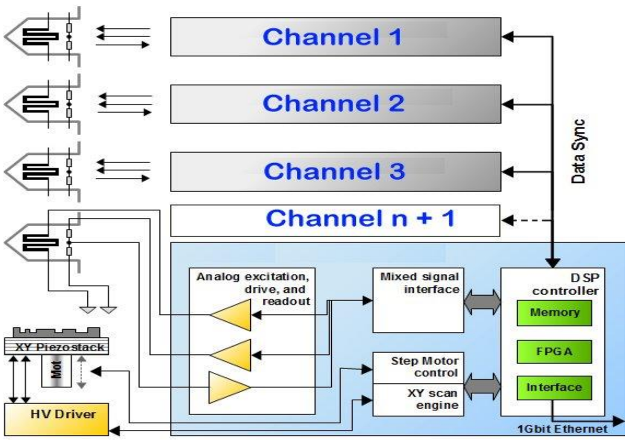

Figure 2. FPGA multi-channel controller.

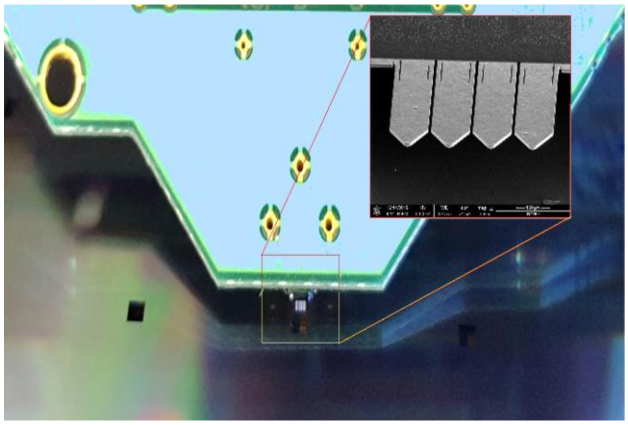

Figure 3. Set-up of the array holder with 4 cantilever.

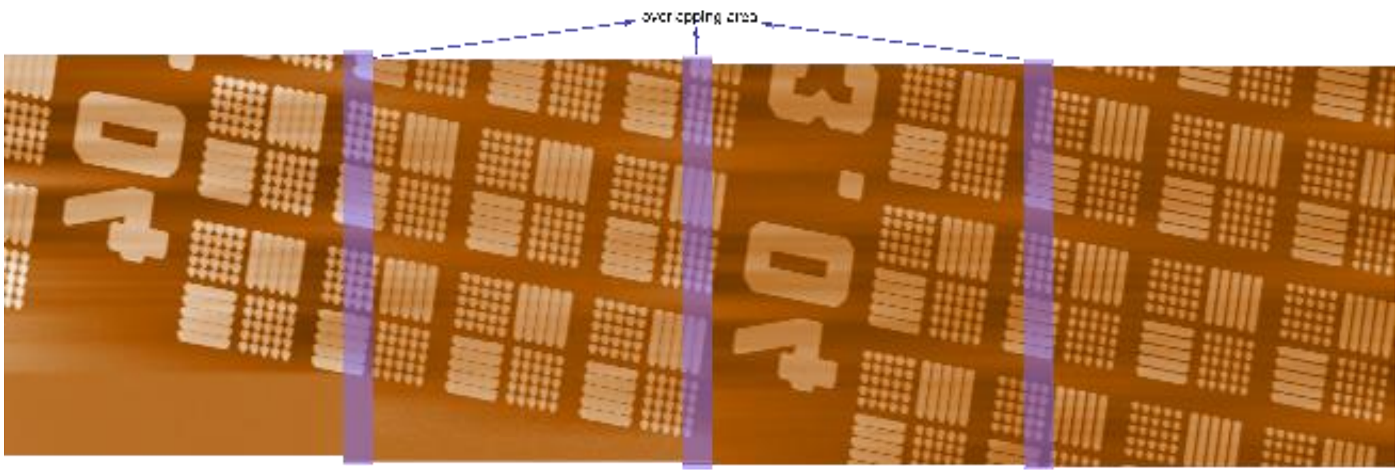

Figure 4. AFM image obtained with array of four self-transduced und self-sensing cantilever. The imaged field is with size of 500 µm x 135 µm where every sub-field is 135 µm x 135 µm large. The overlap between the fields is 10µm. The composite AFM image consists 1.048.576 pixels attained in 126 seconds with four cantilever in non-contact-mode simultaneously.