

# Invited: **Scanning Probes for Nanomanufacturing**

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A desired concept for nano-manufacturing is to create flexible, “top-down/ bottom-up” technology that can be used to build complex systems of complex nanoelectronic or nanomechanical devices. Fabricating of these future devices in nanoelectronics, nanophotonics, and nanoelectromechanical systems requires lithography at the single nanometer level. To make the basis for achieving this concept, we will establish sustainable lithographic principles for reproducible sub-5nm manufacturing of nanostructures with unique capability based on single electron or quantum effects and may be essential to create a ‘beyond CMOS’ generation of electronic devices.

The flexibility inherent in Scanning Probe Technique offers broad possibilities for fast SPL-based nanomanufacturing and direct analysis nanoelectronic devices. A Scanning Probe Lithography (SPL) approach works like miniaturized electron-beam system. To move beyond unique nanofabrication capabilities the following expectations must be considered to enable sustainable single nanometer manufacturing: (i) The generation, placement, overlay alignment, and inspection of the lithographic nanostructures must be accomplished in a precise, reproducible, controlled, and sustainable manner; (ii) The SPL cantilever has to be very small allowing high speed “writing” and “reading” (Figure 1 and 2); (iii) SPL-tip must perform to specification over their expected tip lifetimes (tip-wear); (iii) SPL must be scalable up to the required throughput and yield [1].

Moreover, in this paper, we describe also the design, fabrication, and testing of small active and passive cantilever probes for scanning probe microscope (SPM) and scanning probe lithography (SPL) applications [3-6]. Our active cantilevers are highly integrated [5]. We advance well beyond the today established technology for functional tip arrays in two important respects. First, our cantilevers incorporate actuation and sensing directly onto the cantilever itself. Rather, we take advantage of high performance cantilever technology that has been developed and demonstrated previously within our team (Fig. 1 and 2). Our cantilevers are built with a thermal-bimorph actuator structure. A 2DEG deflection sensor is also integrated into each cantilever and it is carefully thermally isolated from the heater/actuator and designed for minimum electronic cross-talk and capable to measure cantilever thermo-mechanical noise. Further, active Q control, that changes the actuator signal based on the current cantilever vibration sensor signal, is applied to these cantilevers in order to alter their dynamic behavior. In opposite to structural changes on the cantilever beam directly, this technique is flexible and the Q-factor can be tuned in an instance.

This talk will review progress towards Scanning Probes for nanometer scale lithography including sub-5nm precise pattern generation, pattern overlay alignment and measurement constitutes as essential pre-requirement for beyond CMOS device fabrication. Besides the high resolution capability, also economic factors like throughput, cost of ownership, and reliability of the SPL-lithographic method and the SPL-tool (Figure 4) will be presented.

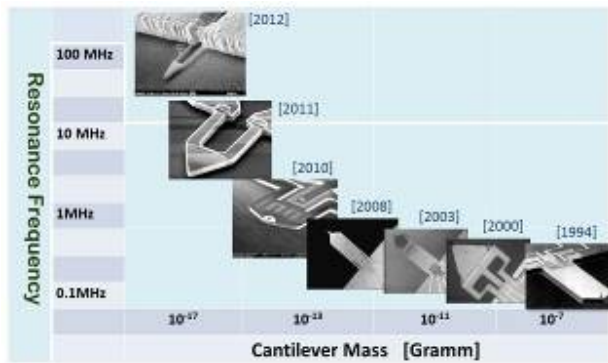


Figure 1. Development of active SPM cantilevers.

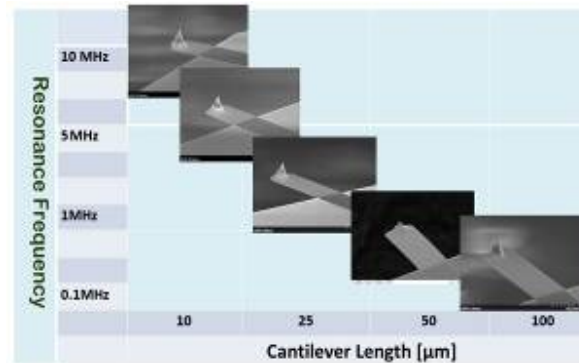


Figure 2. Development of passive SPM cantilevers.



Figure 3. Principle of the Scanning Probe Lithography (SPL) system using a self-development, positive/negative-tone closed loop technique on calixarene-based molecular resist. The same cantilever are used for direct FN-nano-writing, AFM-imaging, pre- and post-imaging (litho-inspection) as well as for pattern overlay alignment.



Figure 4. Image of the tool for scanning probe lithography using FN-low-energy electron emission based on 10x10 $\mu$ m scan field top-scanner and 100x100mm bottom-stage for step and repeat operation in closed-loop mode. The same self-actuated, piezoresistive cantilever (see Figure 1) are used for imaging and lithography.

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