Single-chip Scanning Probe Microscopes

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Oral presentation preferred – Sensors and Sensor Systems

Summary

We present the world's first single-chip Atomic Force Microscopes (sc-AFMs) and Scanning Microwave Microscopes (SMMs). These instruments contain all of the actuators and sensors required to obtain an image on a single CMOS-MEMS chip. Dynamic AFMs, SMMs, conductive AFMs, and Scanning Thermal Microscopes (SThMs) that occupy a $0.25mm^3$ volume have been designed, fabricated and characterized. The microscopes obtain 1nm vertical resolution over a 100µm x 10µm scan range under ambient conditions without vibration or acoustic isolation. This work represents a 1,000,000x volumetric reduction, a 100x cost reduction, and vastly improved stability and ease-of-use when compared to the state-of-the-art. The first sc-AFM product is intended for low-cost applications such as high-school and undergraduate education and metrology for precision machined components. The unprecedented low price of the instrument may enable new applications; however, the elasticity of the global SPM market is not well understood.

Motivation and results

SPMs are widely regarded as workhorse instruments in nanoscience but they have not been adopted for industrial metrology, in part because of their large form factor, poor stability, high cost, and low throughput. It has long been known that miniaturization of SPMs improves their stability and speed, but the use of laser-based position sensing and piezoceramic-based positioning systems have precluded smaller AFMs from entering the market. The CMOS-MEMS technology platform enables wafer-scale arrays of AFMs with high throughput and improved stability at a cost that is commensurate with semiconductor and hard-disk metrology tools.

The design of single-chip SPM's leverages the versatility of a maskless, 2-step MEMS process that makes use of the back-end-of-line layers in a CMOS process. Several of the components of these instruments are shown in Figure 1 below. An sc-AFM die pictured on a fingertip is shown in Figure 2. A low-cost system with interchangeable sc-AFMs is presented in Figure 3, with imaging results shown in Figure 4.

One goal of our work is to enable inexpensive, high-throughput arrays of scanning probe microscopes to address today's metrology needs. Because the scanners are integrated into each SPM in the array, the imaging bandwidth remains constant as the array is scaled to larger sizes. Single chip SPM's stand to benefit from the favorable scaling laws associated with the miniaturization of scanners. Smaller scanners should have improved stability, immunity to thermal drift and ambient vibration, higher bandwidth, and lower cost. Large arrays of these devices may offer a compelling solution to large area metrology of nanometer-scale manufactured products.

Word count: 404

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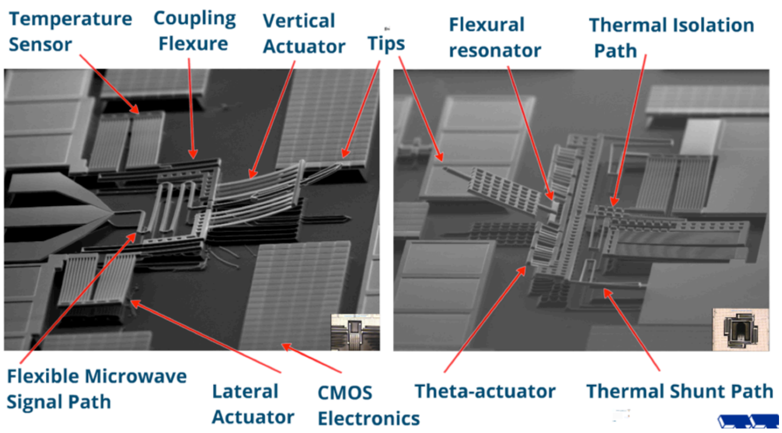

Figure 1: Various components of single-chip scanning probe microscopes

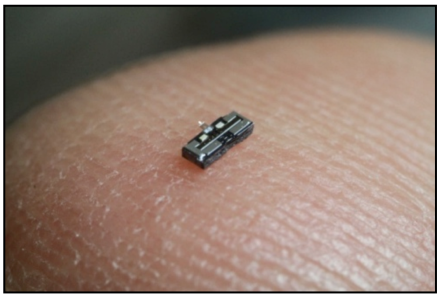

Figure 2: Single-chip atomic force microscope on a fingertip

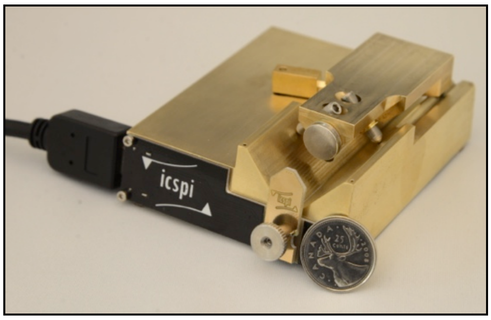

Figure 3: Low-cost AFM system

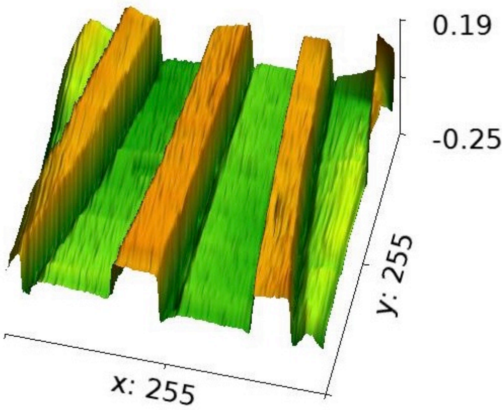

Figure 4: Topography image of a 100nm AFM calibration standard obtained with an sc-AFM