Abstract

The dynamic mode atomic force microscope (AFM) is a versatile tool that uses a resonantly excited micro-cantilever probe to obtain a sample's topography and to characterize its material properties. While a number of useful techniques have been developed for interacting with the sample, conventional AFM probes and AFM systems do not facilitate their effective implementation. This thesis investigates the design of specialized AFM probes and the development of a novel probing system that improves the speed of imaging and enhances the sensitivity to material properties in dynamic mode AFM.

In order to perform high speed imaging, an integrated high-bandwidth magnetic actuation system, comprising a special probe and an actuator, is designed and developed. Subsequently, the actuation system is fabricated and evaluated using an in-house developed measurement system to possess an eigen-frequency of 104 kHz and a range of 225 nm. In aqueous medium, the probe is shown to suffer 3 times lesser reduction in eigen-frequency compared to a conventional probe of similar eigen-frequency in air.

In order to achieve enhanced sensitivity to material properties, a systematic approach is proposed to design and fabricate probes with specified eigen-frequencies. The proposed approach is employed to design and develop a flexural harmonic probe with eigen-frequencies in the ratio 1:2 and a torsional harmonic probe with eigen-frequencies in the ratio 1:2:3. The experimentally evaluated eigen-frequency ratios are shown to match the specifications to within 0.4% and 2% respectively. Further, harmonic probes with exchangeable tips are proposed and a prototype probe is fabricated and evaluated. The developed harmonic probes are shown to be significantly more sensitive to tip-sample forces.

To effectively exploit the high speed and sensitivity of the developed probes, a custom AFM system is designed and developed in-house. The AFM includes a novel Z-magnetic actuation system having bandwidth in excess of 3 MHz and an XY nano-positioning system suitable for video-rate imaging. A novel measurement system based on optical beam deflection is developed and evaluated to measure XY-motion of the positioner. High speed control hardware based on Field Programmable Gate Array (FPGA) has been used for data acquisition and real-time control, with update rates of more than 5 MHz. The developed system is demonstrated to enhance the positioning bandwidth of the high-speed AFM probe, and subsequently employed in high-speed dynamic mode AFM imaging at rates upto 1.25 frames/second. Finally, the potential of the developed system for video-rate dynamic mode AFM imaging, and in-situ material characterization is discussed.