1 Publishable summary

Atomic force microscopy (AFM) has become one of the most important microscopy techniques for micro- and nanotechnology. With the AFM it is possible to resolve very small things, such as single molecules or eve atoms. This makes it one of the highest resolution microscopes in existence. A 3D representation of the sample topography is created by scanning a sharp sensor probe (i.e. a cantilever with a sharp tip) over the surface, and recording for each point the height of the sample (insert Fig. 1,A). In this way, a wide variety of samples can be imaged with nanometer resolution. The fact that samples can be imaged in a broad range of environments (vacuum, air, fluids) is a unique feature of the AFM. This enables its use in a broad range of applications. Its uses range from imaging hard samples with sub-nanometer resolution, for example in process control and semiconductor fabrication, to imaging very soft samples in life science (see Fig. 1,B). In addition to measuring the topography, several other quantities can be measured. With the right combination of cantilever and operating mode, mechanical properties, electronic properties, magnetic properties, and biological binding affinity can be measured with nanometer resolution.

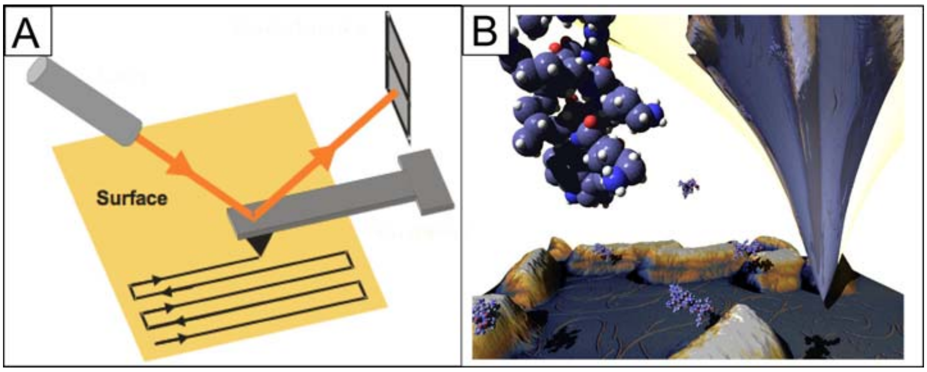

Fig. 1: Basic principle of AFM imaging. A) A sharp tip at the end of the cantilever is raster scanned over the sample surface and thereby detects the sample topography. B) An artistic rendering of a cantilever over real 3D AFM images of E.Coli bacteria.

Cantilever technology and micro-fabrication have been key driving forces for the success of AFM and its diverse uses. Batch processing (making hundreds of cantilevers by processing a single wafer) allowed the fabrication of high quality cantilevers at a low price. Using the techniques available in micro fabrication, cantilevers specially designed for specific applications can be made, having a wide variety of stiffness and resonance frequencies.

While AFM has many advantages, it also has a few severe drawbacks. One is the long time that is required to record an image (typically 1-20 minutes).This reduces throughput in industrial process control, and it impedes imaging of samples that change over time (which is often the case in biology). The main bottleneck is the speed at which the cantilever can detect a change in topography as it is scanned over the sample. Therefore, one of the enabling technologies for increasing the speed of AFM was the development of small AFM cantilevers, which have up to 500 times less mass than conventional large cantilevers (small cantilever: width <10um, length 15-30um, thickness 0.1-0.3um; conventional large cantilever: width 30-100um, length 60-200um, thickness 0.5-5um). With these cantilevers, high quality rapid images can be taken even on soft biological samples in fluid. SCL-Sensor.Tech.Fabrication GmbH was the first commercial manufacturer of the small AFM cantilevers, which have resulted in a significant increase in scanning speed and several high profile publications. Using cantilevers with the reduced size however, has its difficulties, mainly in how the bending of the cantilever can be detected.

The conventional way to measure the cantilever sensor deflection is by using a laser beam, which is reflected of the back of the cantilever, see Fig. 2. Most AFMs cannot focus the laser down small enough to use the new generation of small cantilevers, and specialized AFM instruments have to be used for these small cantilevers. This has thus far limited the wider use of high speed AFM beyond a small group of specialist labs.

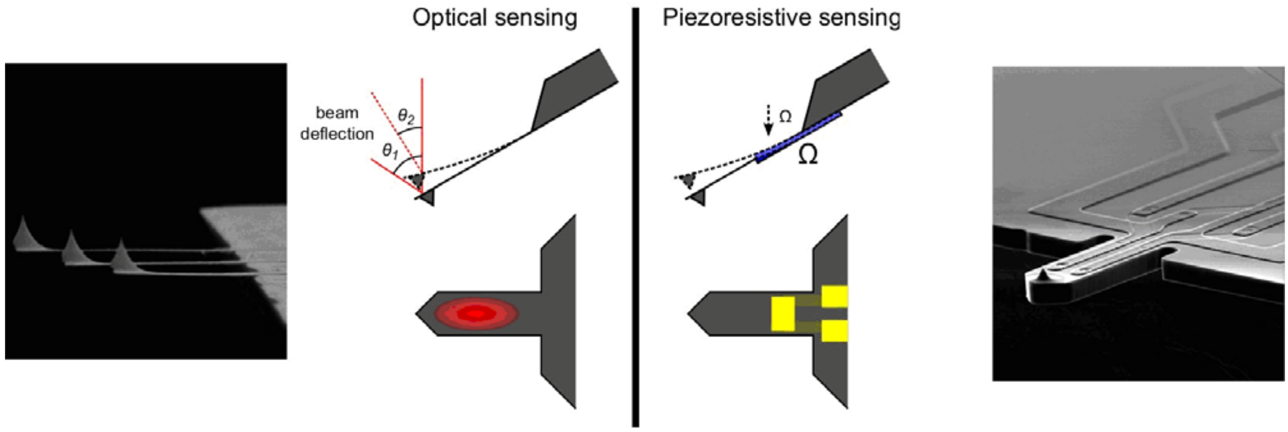

Fig. 2: Traditional methods for measuring the deflection of an AFM cantilever. optical deflection: a laser beam is reflected of the back of the cantilever at an angle θ1, when the cantilever is deflected by the surface topography, the laser beam is deflected at an angle θ2. Piezoresistive: A piezoresistive element is fabricated at the base of the cantilever. This element changes its resistivity when it is bent with the cantilever. This change in resistance can be then measured electrically using for example a Wheatstone bridge configuration.

To circumvent the need for the optical components, small cantilevers with integrated sensors have to be developed. The **main objective** of the ALBICAN project is to develop such self-sensing and small cantilever technology. In order to make the self sensing cantilevers small and soft enough, a different self-sensing technology based on nanogranular tunneling resistors (NTRs) will be developed to make very small cantilevers for high speed AFM and biological applications.

The scientific and technical approach of the ALBICAN project has been based on three main categories of performance criteria for AFM cantilevers, in which technological advancement are possible through the development and integration of NTR sensing elements on small AFM cantilevers. In the individual parts of the project, the cantilever size, as well as the NTR sensor performance is being optimized individually. However, to reach the high speed and sensitivity performance that is required, much effort is put into designing both the cantilever as well as the sensor, such that the strength of both approaches is leveraged through their combination.

A. **Sensor Performance:** this category deals with the performance of the sensing of the cantilever deflection only.

B. **Cantilever Geometry:** this category deals with determining the best shape and mechanical characteristics of the cantilevers that are to be outfitted with NTR sensors.

C. **Usability:** this category deals with how well cantilevers that use this technology are suited for specific tasks.

The work in this project is organized in seven interconnected work packages. Working according this operational concept significant progress has been made towards the overall project goal. In the first phase of the project, first prototype cantilevers have been fabricated and equipped with NTR deflection readout. Using these cantilevers, the first AFM images with NTR sensors have been recorded. Furthermore, materials fabrication technologies for the next generation cantilevers have been developed.

The achieved interim results provide all the necessary requirements to perform the next steps that were planned for the project. At the end of the project, we expect to have developed all necessary technologies to fabricate small, self-sensing AFM cantilevers that allow imaging speeds well beyond what is possible with conventional cantilevers. These cantilevers will not require specialized optical readout components, and can therefore be used in a broad range of existing and future AFM instruments. This will help to bring fast scanning AFM to a broader user base in both research and industry. In addition to this, the developed technologies can be used to further miniaturize the cantilevers to sizes far beyond the sizes that were previously possible (due to the optical detection limit that is currently used in high speed AFMs). This will allow completely new approaches for research into ultra high speed AFMs in the future.