High Speed Atomic Force Microscope

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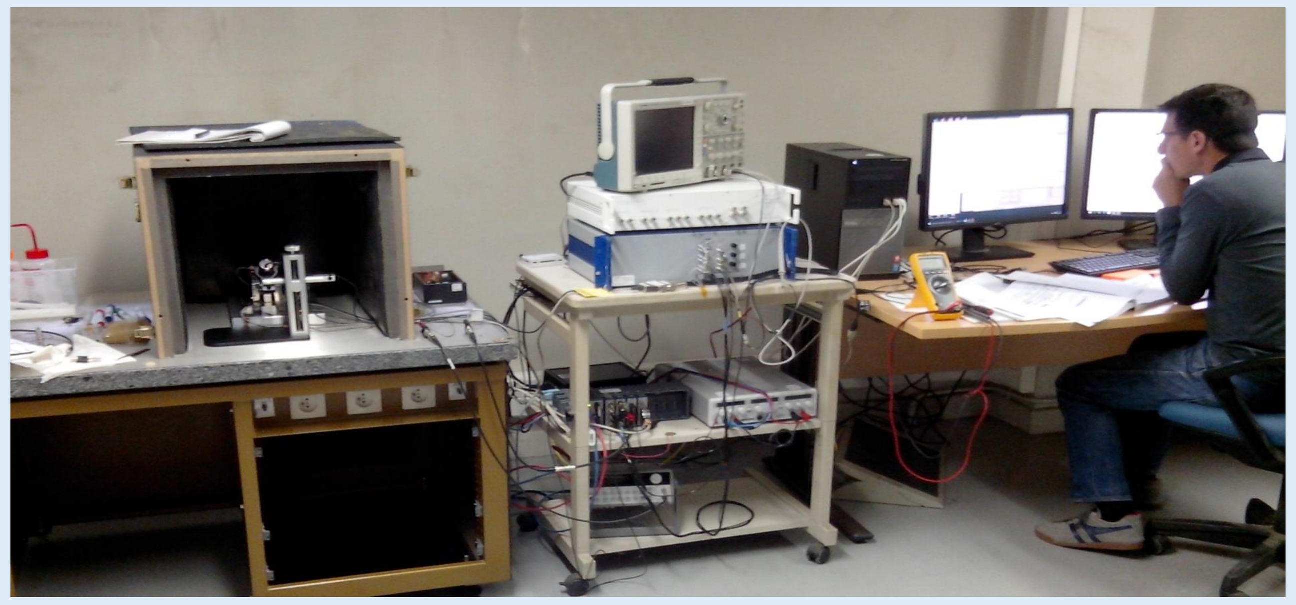
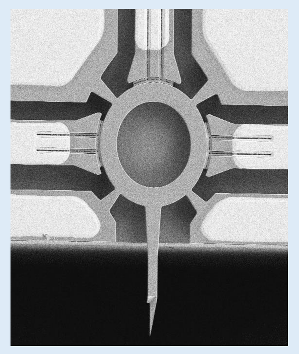
Summary

Atomic Force Microscope (AFM) is now a common tool for material analysis in the academic and industrial areas because it enables non-destructive high-resolution images of nanometric objects. However, a main drawback is **the slow scan rate** that hinders many potential applications. Recently, breakthroughs have been achieved in AFM sensors based on MEMS technology, allowing to extend AFM operation in terms of measurement bandwidth and data acquisition. The present work focusses on **developing an electronic controller** for AFM featuring the **wide bandwidth and the fast data processing rate** required to enable the exploitation of the full potential of MEMS AFM sensors.



Global view of High Speed AFM setup at LAAS-CNRS, Toulouse (France)

High frequency AFM probes (MEMS technology)



AFM probes used in the present work were developed at IEMN-CNRS (Lille, FRANCE) and are now available from Vmicro SAS. A silicon ring holding a nanotip vibrates according to the elliptical resonance mode shape at about 13 MHz. **Capacitive electromechanical transducers** are integrated for driving and sensing the nanotip vibration. Typical measurement resolutions are 1.5 $\mathrm{fm}/\sqrt{\mathrm{Hz}}$ in displacement and 0.5 $\mathrm{pN}/\sqrt{\mathrm{Hz}}$ in force.

www.vmicro.fr

Contact and informations at :
https://www.laas.fr/projects/olympia

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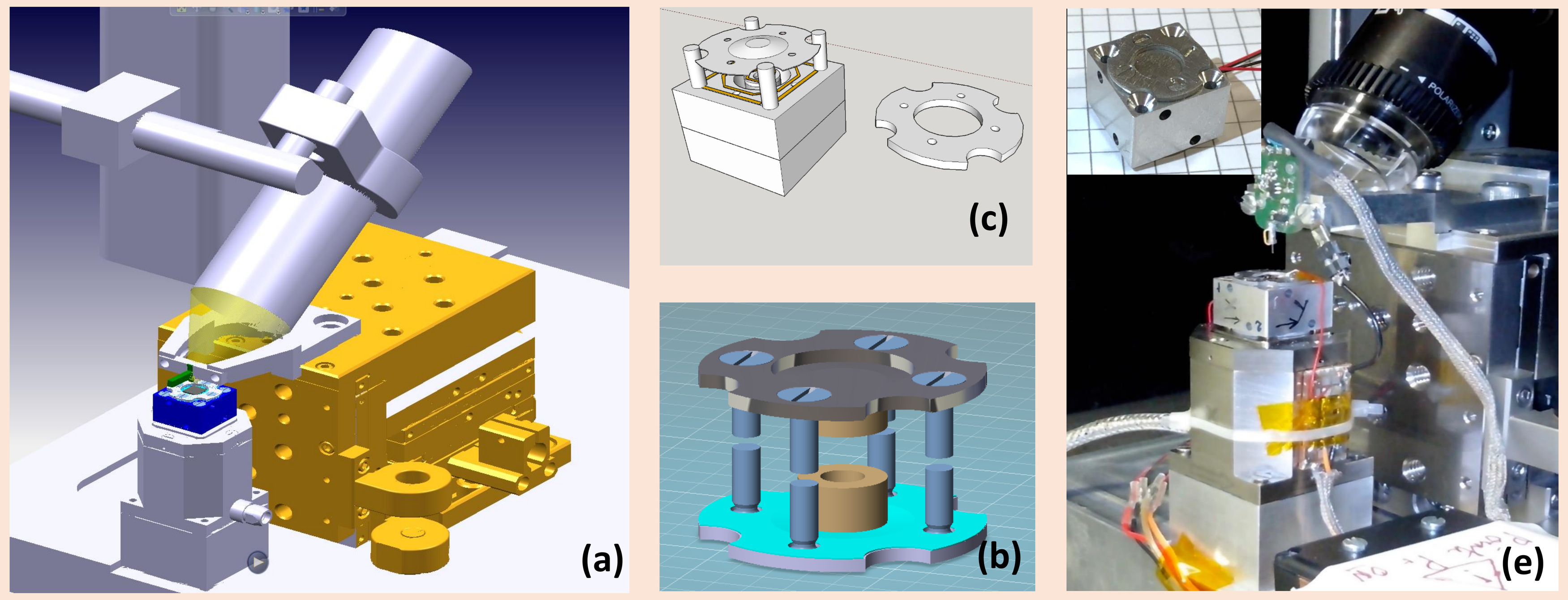
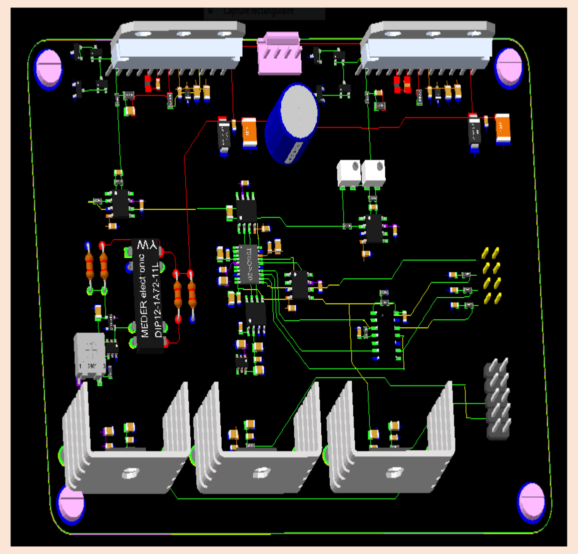
Microscope



Making of AFM microscope :
(a) and (e) : 3D drawing and photo of the microscope assembled.
(b) and (c) : design and making of fast Z actuator, wich consists of 2 piezoelectrics ceramics in opposite move, enclosed and glued between preload plates made of stainless steel.

Electronics



Homemade electronic board to drive the fast Z actuator, consists of a 20-bit DAC and two (100V, 500 kHz) amplifiers to drive the two opposite ceramic piezos. The 20-bit word is generated by NI-9401 digital ouput module via SPI bus at 40MHz.

Piezo Z control Loop timing

Probe voltage acquisition 16 bits → PID calculation 32 bits → DAC command 20-bit word / Data -> FIFO to RTos

2.2 µs + ~ 0.8 µs + 1 µs

FPGA : microscope Z feedback operations take about 4 µs to complete. It executes every 1 µs with pipelining method.

Software architecture

PC – LabVIEW 2016, **QMH project**

UI@ 10 ms
- R/W network streams from RT
- Unbundle datas
- Convert data to physical units (m,V)
- Averaging per pixel

UI@ 100 ms
- Display scaled data
- Display scan images

- UI management
- Save image files
- Control USB motor for approach

Data 80 Mbit/s

Messages

Real-Time Controller – LabVIEW RT, QMH model

RT@ 5 ms non determ.
- R/W stream to UI

RT@ 1 ms deterministic
- Read data from FPGA

FPGA – LabVIEW FPGA

Z control loop @1µs pipelining
- Probe signal acquisition
- PID calculation with gain schedule
- Piezo Z command (20-bit word to external DAC)

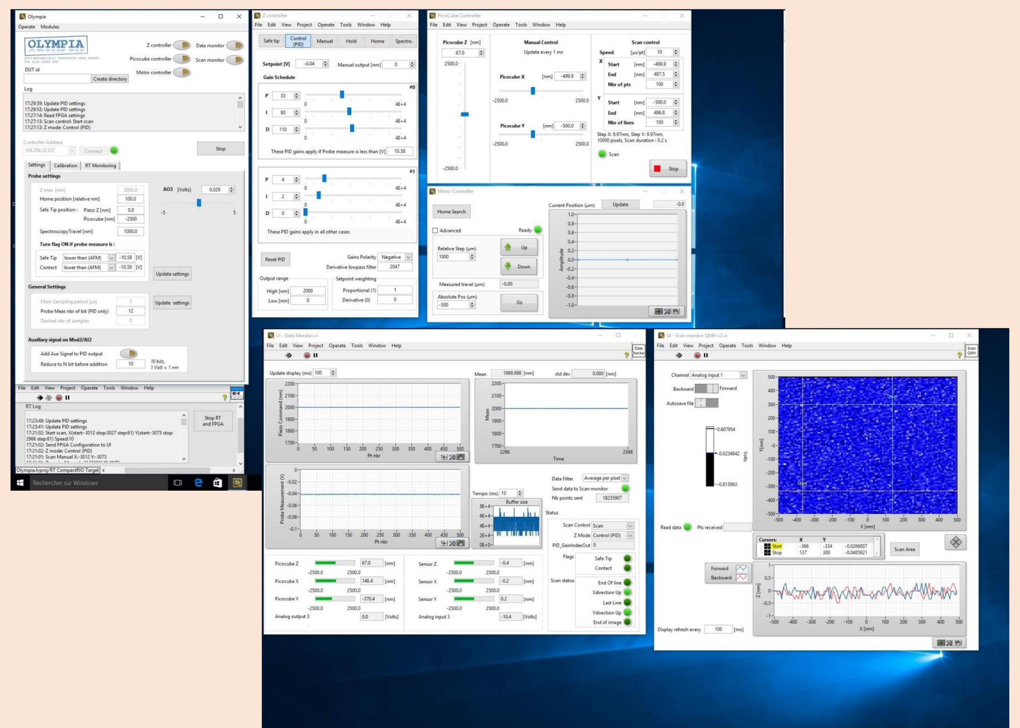
Scan control @10µs or more
- Scan X, Y via Analog Outputs
- Read X, Y position sensors (AIs)
- Watchdog @40MHz

NI CompactRIO configuration

The controller of the AFM microscope is based on a 8-slot CompactRIO NI-9035.

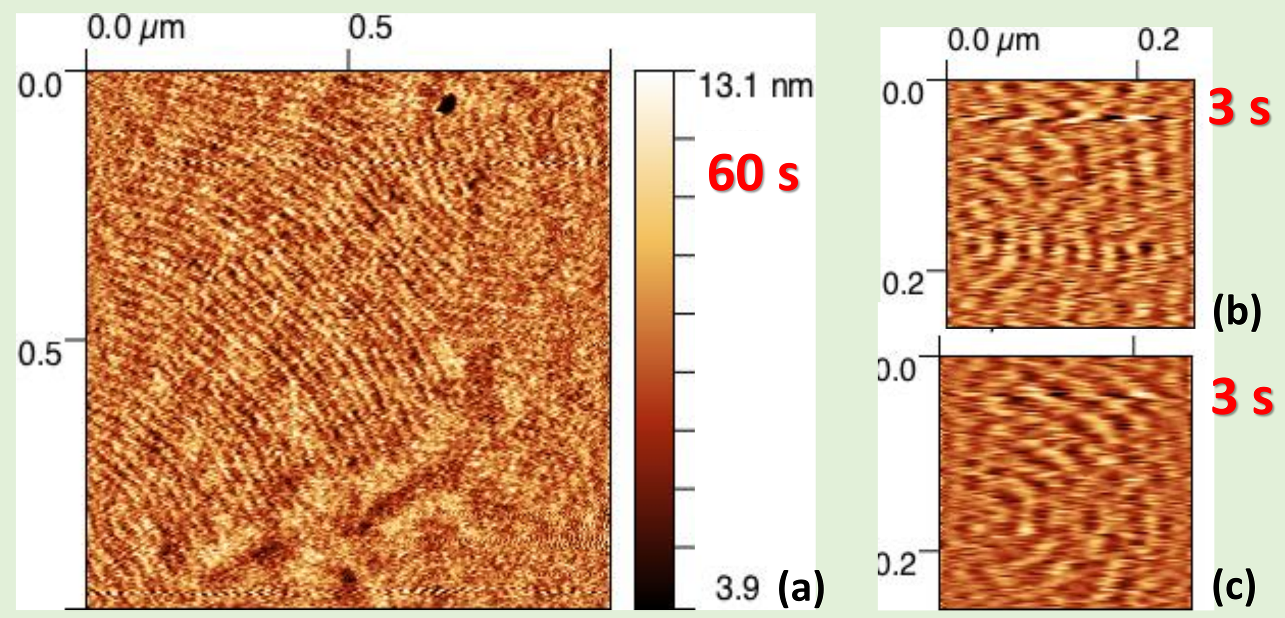
Compact-RiO NI-9035	AIs NI-9215	AIs NI-9223	AOs NI-9263	DIOs NI-9401
	100 kSa/s 16 bits	1 MSa/s 16 bits	100 kSa/s 16 bits	
	↑ **X, Y, slow Z** position sensors	↑ **Probe signal**	↓ **X, Y,slow Z** Scan posit. command	→ Homemade electronics: **DAC** 20 bits BW 1MHz → **Amplifier** 100 V BW 500 KHz → **Piezo Z comand**

2-screen wide User Interface

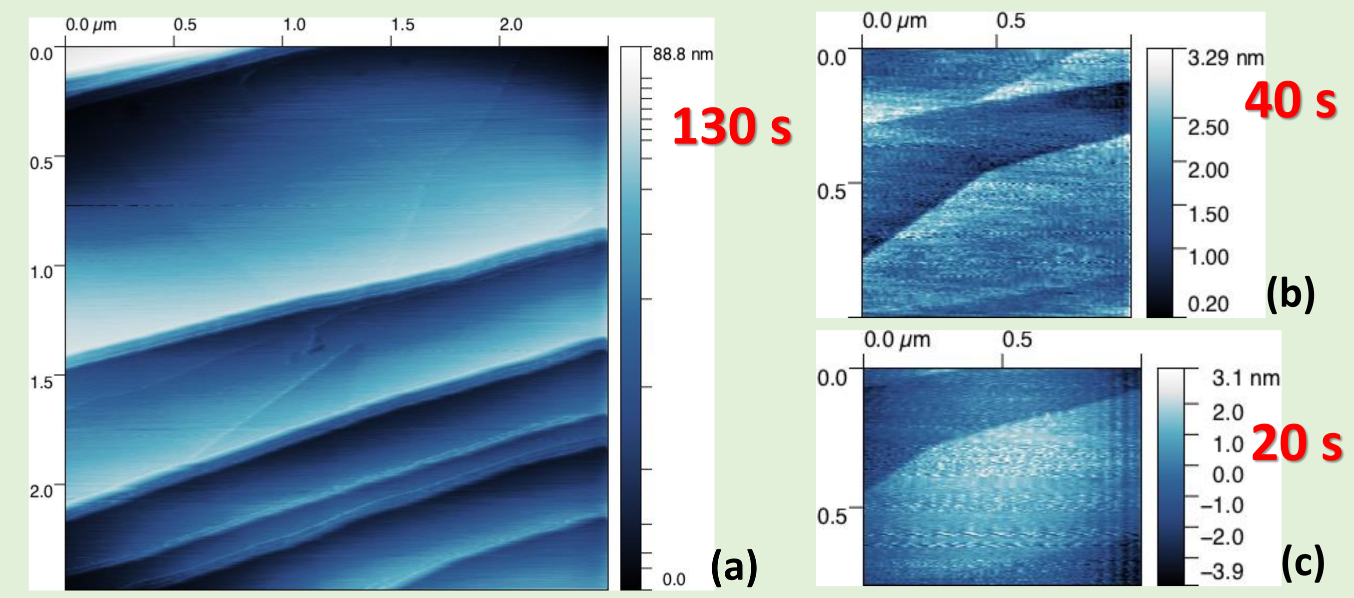


Software performance

	Small image 1k pixels	Biggest image 3M pixels
Scan duration	0.02s (50 images/s)	60s
Binary file size	47 KB	140 MB



Topography images of diblock copolymers in FM-AFM mode
(a) Image 1 × 1 µm (256 × 256 pix.) acquired in 60 s. (b) and (c) Images forward and backward 250 × 250 nm (128 × 128 pix.) acquired in 3 s.
The topographic contrast is due to elasticity contrast of copolymers strips.



Images of graphite HOPG steps in AM-AFM mode
(a) Image 2.5 × 2.5 µm (512 × 512 pix.) acquired in 130 s. (b) Image 1 × 1 µm (200 × 200 pix.) acquired in 40s. (c) Image 1 × 1 µm (200 × 200 pix.) acquired in 20 s.