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High Speed Atomic Force Microscope
Nicolas Mauran¹, Denis Lagrange², Xavier Dollat³, Laurent Mazenq³, Lucien Schwab³, Jean-Paul Salvetat⁴, Bernard Legrand³

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.

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 nm/√Hz in displacement and 0.5 pN/√Hz in force.

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

Data 80 Mbit/s
Messages

UI@ 100 ms
- Display scaled data
- Display scan images
- UI management
- Save image files
- Control USB motor for approach

Real-Time Controller – LabVIEW RT, QMH model
- RT@ 5 ms non determ.
- RT@ 1 ms deterministic
- R/W stream to UI
- 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

Software performance

Scan duration
- Small image 1k pixels: 0.02s
- Biggest image 3M pixels: 60s

Binary file size
- 47 KB
- 140 MB

Piezo Z control Loop timing
- Probe voltage acquisition 16 bits
- PID calculation 32 bits
- DAC command 20-bit word
- Data → FIFO to RTos

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

Contact informations at:
https://www.laas.fr/projects/olympia
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High Speed Atomic Force Microscope

Topography images of AlInP/GaAs heterostructure: (a) Image 2.5 x 2.5 µm (312 x 312 pix) acquired in 40 s. (b) and (c) images forward and backward. The topographic contrast is due to elasticity contrast of copolymers strips.

Images of graphene HOPG steps in AFM modes: (a) Image 2.5 x 2.5 µm (312 x 312 pix) acquired in 130 s. (b) Image 1 x 1 µm (200 x 200 pix) acquired in 40s. (c) Image 1 x 1 µm (200 x 200 pix) acquired in 20s.

NI CompactRio configuration
- The controller of the AFM microscope is based on a 8-bit CompactRio NI-9035.
-CompactRio NI-9035
- Analog I/O: 100 µA
- 16-bit: 100 kHz
- Digital I/O: 2.5 V
- 16-bit: 10 MHz
- 2.5 MHz
- FPGA: @40MHz

2-screen wide User Interface
- Image acquisition
- User interface
- Calibration
- Measurement
- Edit
- View
- Workspace
- Preferences
- Help
- DAC
- 20 bits
- 160 MSa
- 9223
- Amplifier
- 100 V
- 16 bits
- 100 kHz
- 9223
- Piezo Z command
- 1.5 µm
- 12 bits
- 100 kHz
- 9223

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

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