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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 nanoobjects. 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 focuses 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.

Contact and informations at: https://www.laas.fr/projects/olympia
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Global view of High Speed AFM setup at LAAS-CNRS, Toulouse (France)

High Speed Atomic Force Microscope

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

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-deterministic
Read data from FPGA

RT@ 1 ms deterministic

FPGA – LabVIEW FPGA

Probe voltage acquisition
PID calculation 32 bits
DAC command 20-bit word

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-bit CompactRIO: NI-9035.

2-screen wide User Interface

DAC command

Amplifier 100 V SW 750 kHz

Piezo Z command

Compact-RIO
NI-9035

Analog inputs
NI-9215
100 kHz
16 bits

Analog outputs
NI-9232
500 kHz
16 bits

Digital I/Os
NI-9263
200 MHz
16 bits

DI-9261
200 MHz
16 bits

Home-made electronics

X, Y, slow Z
position sensors
Probe
signal

X, Y, close Z
Scan position
command

DAC
20 V SW 500 kHz

Homemade electronic board to drive the fast Z actuator, consists of a 20-bit DAC and two (102V, 500 kHz) amplifiers to drive the two opposite ceramic plates. The 20-bit word is generated by NI-9401 digital output module via SPI bus at 40MHz.

Software performance

<table>
<thead>
<tr>
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<th>Small image 1k pixels</th>
<th>Biggest image 3M pixels</th>
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<tbody>
<tr>
<td>Scan duration</td>
<td>0.02s (50 images/s)</td>
<td>60s</td>
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<tr>
<td>Binary file size</td>
<td>47 KB</td>
<td>140 MB</td>
</tr>
</tbody>
</table>

Topography images of diblock copolymers in the AFM mode
(a) Image 3 x 1 μm (512 x 256 pix.) acquired in 60 s. (b) and (c) images forward and backward 200 x 200 μm (0.08 x 0.08 pix.) acquired in 3 s.

The topographic contrast is due to elasticity contrast of copolymers strips.

Images of graphite HOPG steps in AFM mode
(a) Image 2.5 x 2.5 μm (512 x 512 pix.) acquired in 130 s. (b) and (c) images forward and backward 100 x 100 μm (0.2 x 0.2 pix.) acquired in 40 s. (c) images 1 x 1 μm (200 x 200 pix.) acquired in 20 s.