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High Speed Atomic Force Microscope

Nicolas Mauran1, Denis Lagrange2, Xavier Dollat2, Laurent Mazenq1, Lucien Schwab1, Jean-Paul Salvetat*, Bernard Le Grand1


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 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 speed AFM probes (MEMS technology)

AFM probes used in the present work were developed at IEMN-CNRS (Lille, FRANCE) and are now available from Vmico 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 data
  - 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

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

- Watchdog @40MHz

Piezo Z control Loop timing

- 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 performance

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

High frequency AFM probes

Images of graphite HOPG

(a) Topography of diblock copolymers in the AFM mode
(b) Image 1 × 1 µm (256 × 256 pixels) acquired in 60 s. (a) and (c) images forward and backward 200 × 200 nm (0.01 × 0.01 pixels) acquired in 3 s.

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