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High Speed Atomic Force Microscope

Nicolas Mauran\(^1\), Denis LaGrange\(^1\), Xavier Dollat\(^2\), Laurent Mazenq\(^1\), Lucien Schwab\(^1\), Jean-Paul Salvetat\(^1\), Bernard Legrand\(^2\)


**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 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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- CRP Dynamic

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

**Real-Time Controller – LabVIEW RT, QMH model**

- **RT@ 5 ms non determ.**
  - R/W stream to UI
  - Display scaled data
  - Display scan images
  - UI management
  - Save image files
  - Control USB motor for approach

- **RT@ 1 ms deterministic**
  - Read data from FPGA
  - Probe signal acquisition
  - PID calculation with gain schedule
  - Piezo Z command (20-bit word to external DAC)
  - Scan control @10µs or more
  - Watchdog @40MHz

**NI CompactRIO configuration**

The controller of the AFM microscope is based on a 8-slot CompactRIO NI-9025.

**Software architecture**

- **PC – LabVIEW 2016, QMH project**
  - UI@ 10 ms
  - R/W network streams from RT
  - Un bundle datas
  - Convert data to physical units (m,V)
  - Averaging per pixel

- **Z control loop @1µs pipelining**
  - Scan X, Y via Analog Outputs
  - Read X, Y position sensors (Als)

- **DIOs**
  - NI CompactRIO
  - NI-9025
    - DAQ-9039 100 kSa/s 16 bits
    - ADC-9223 100 kSa/s 16 bits
  - DAC-9401 200 V

- **2-screen wide User Interface**

**Piezo Z control Loop timing**

<table>
<thead>
<tr>
<th>Probe voltage acquisition</th>
<th>PID calculation 32 bits</th>
<th>DAC command 20-bit word</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.2 µs</td>
<td>~ 0.8 µs</td>
<td>1 µs</td>
</tr>
</tbody>
</table>

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

**Software performance**

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

**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) 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.