Experimental investigation of the formation of nano-indentations in thin polymer films

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Presentation outline

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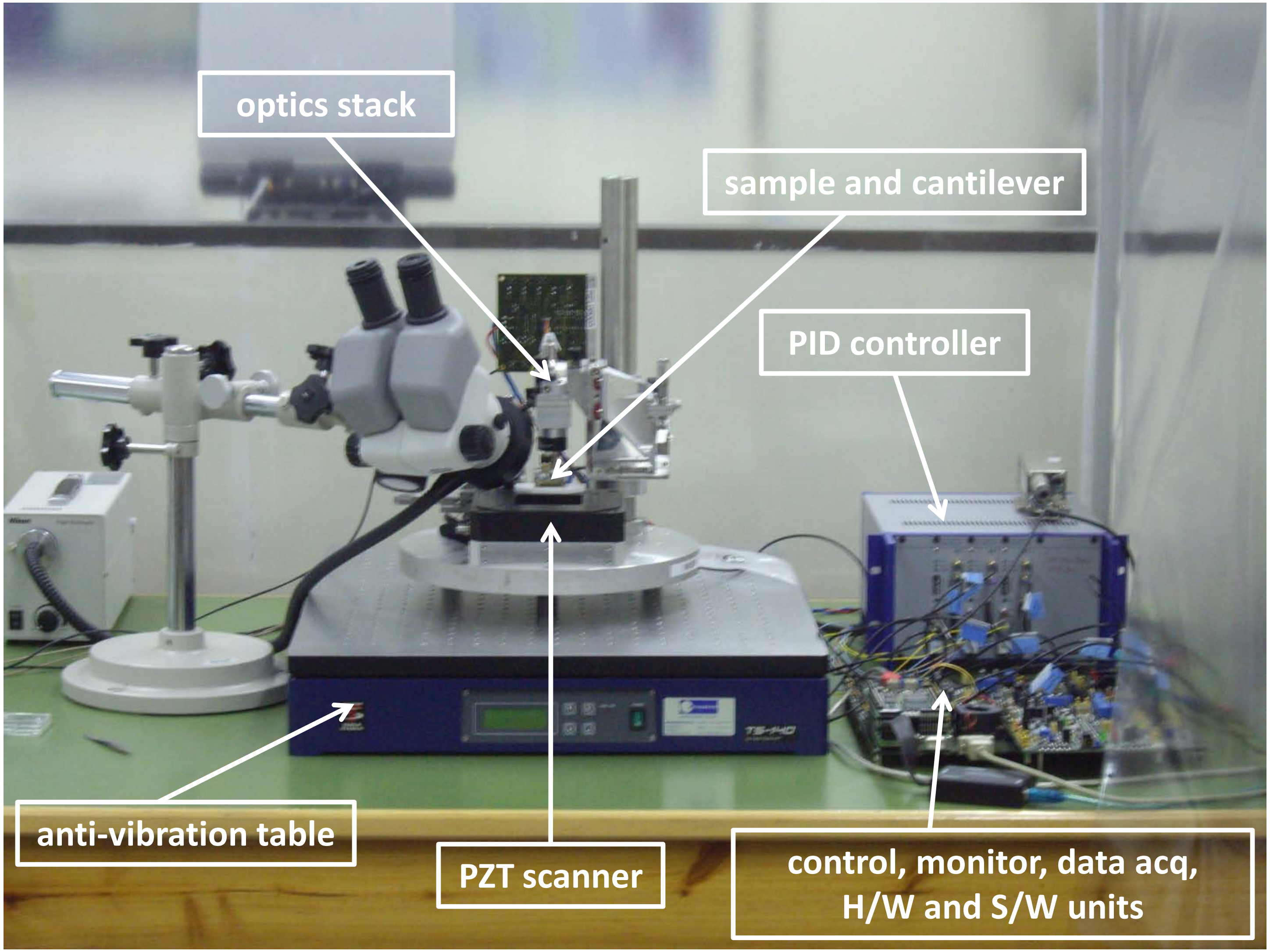
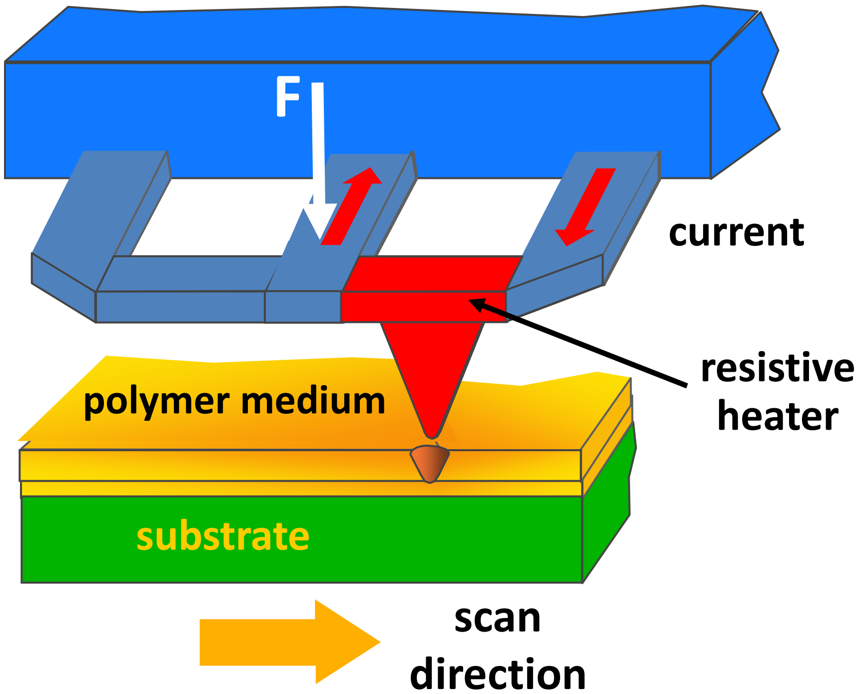
Introduction

- Scanning probes with nanometer-sharp tips have been used extensively the last few years.
  - Nanolithography, imaging, etc
  - Ultra-high-density data storage
- In probe-based data storage, information is stored in the form of nanoscale indentations by locally altering the storage medium’s properties.
  - Polymer shape (thermo-mechanically)
  - Phase change (electrically)
- Investigate the effect of nanopositioning speed on the 3-D shape of indentations created on thin polymer films. <u>Motivation:</u>
  - Analytical model of the indentation (simulation)
  - Accuracy of detecting the stored information (adaptive detection)

AFM Experimental Setup



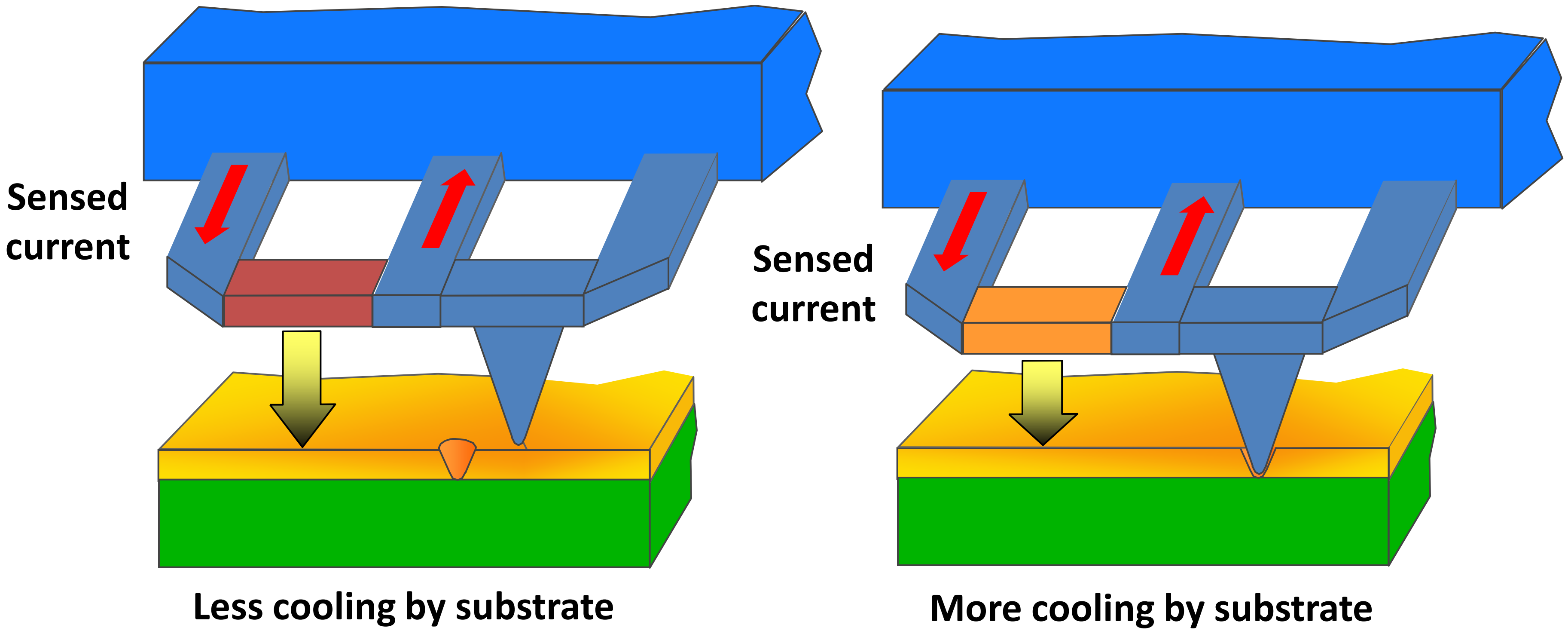
Nano-indentation formation mechanism



Duration:	1µs – 5µs
Heater temperature:	350°C –500°C
Tip temperature:	~ 200°C –300°C
Force :	50nN – 300nN (ESF~ 3V – 10V)

- The current that flows through the resistance heats the cantilever tip.
- An electrostatic force pulse applied between the cantilever and the substrate forces the tip to contact the underlying polymer.
- The heated tip softens the polymer forming an indentation.
- Indentation shape and dimensions:
  - Formation process parameters
  - Cantilever mounting angle
  - **Scanner velocity during formation**
  - Tip apex dimensions (wear) and shape (usually conical)

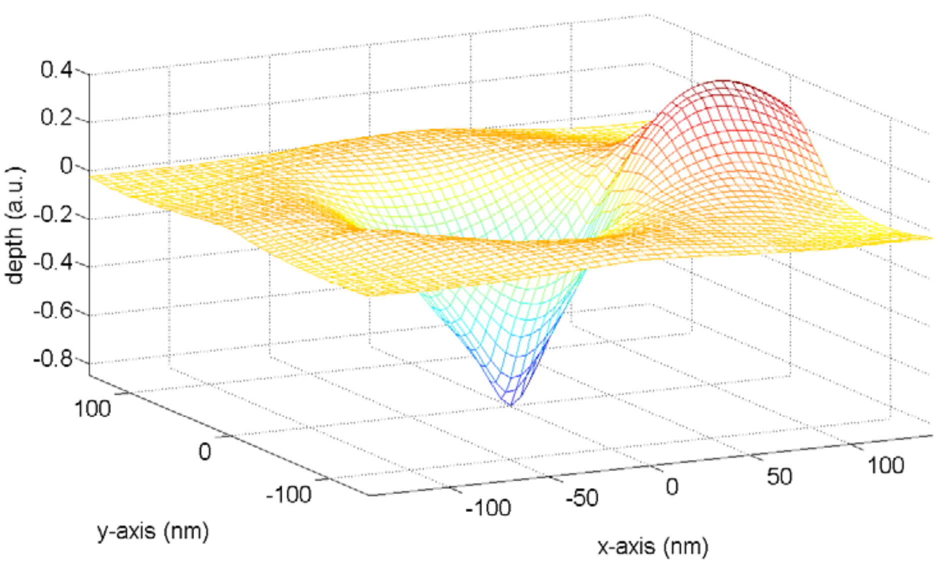
Imaging mechanism: thermo-electrical



- ❑ The temperature of the sensing element determines its resistance.
- ❑ The resistance change over time is detected as a change in the voltage between the two cantilever legs.

3-D indentation model

- Polymer bulges around the edges of the indentation (RIMs).
- Nano-indentations present:
  - asymmetric x-y widths
  - asymmetric x-y RIMs
  - asymmetric x-axis RIMs depending on the direction of motion
- Starting from a two dimensional Gaussian function, a modified two dimensional Laplacian of Gaussian parametric function is derived.



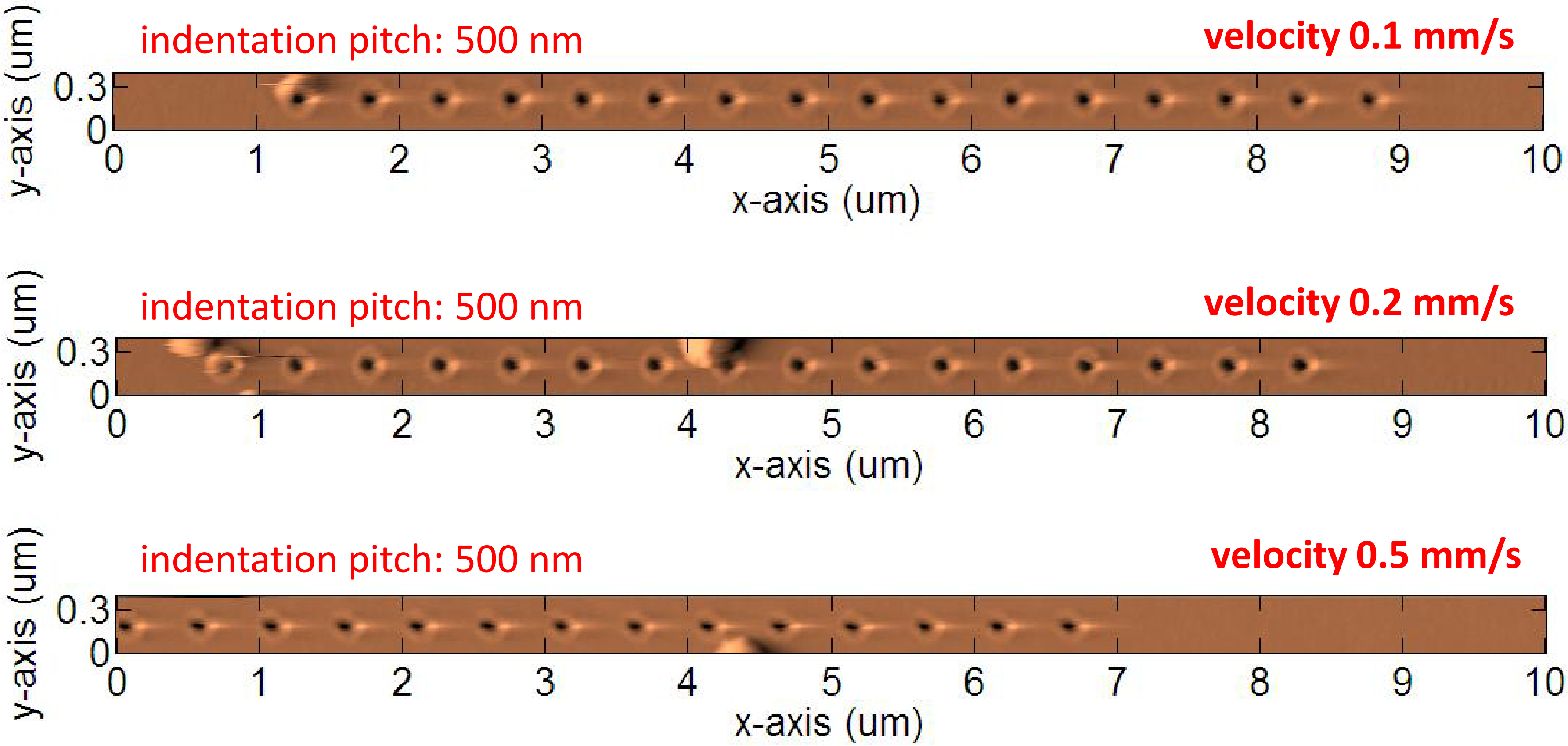
Example indentation obtained from experimental data

The proposed model captures the asymmetric shape of the 3-D indentation:

$$S(x,y) = p_1\left[\frac{p_4\left(1+\left\lceil 0.5(\mathrm{sgn}(x)-1)\right\rceil p_6\right)x^2 - p_2{}^2}{p_2{}^4} + \frac{p_5 y^2 - p_3{}^2}{p_3{}^4}\right]\exp\left[-\left(\frac{x^2}{2p_2{}^2}+\frac{y^2}{2p_3{}^2}\right)\right]$$

where $\boldsymbol{p} = [p_1\ p_2\ p_3\ p_4\ p_5\ p_6]^T$ the vector of the function's coefficients.

Experimental nano-indentation extraction

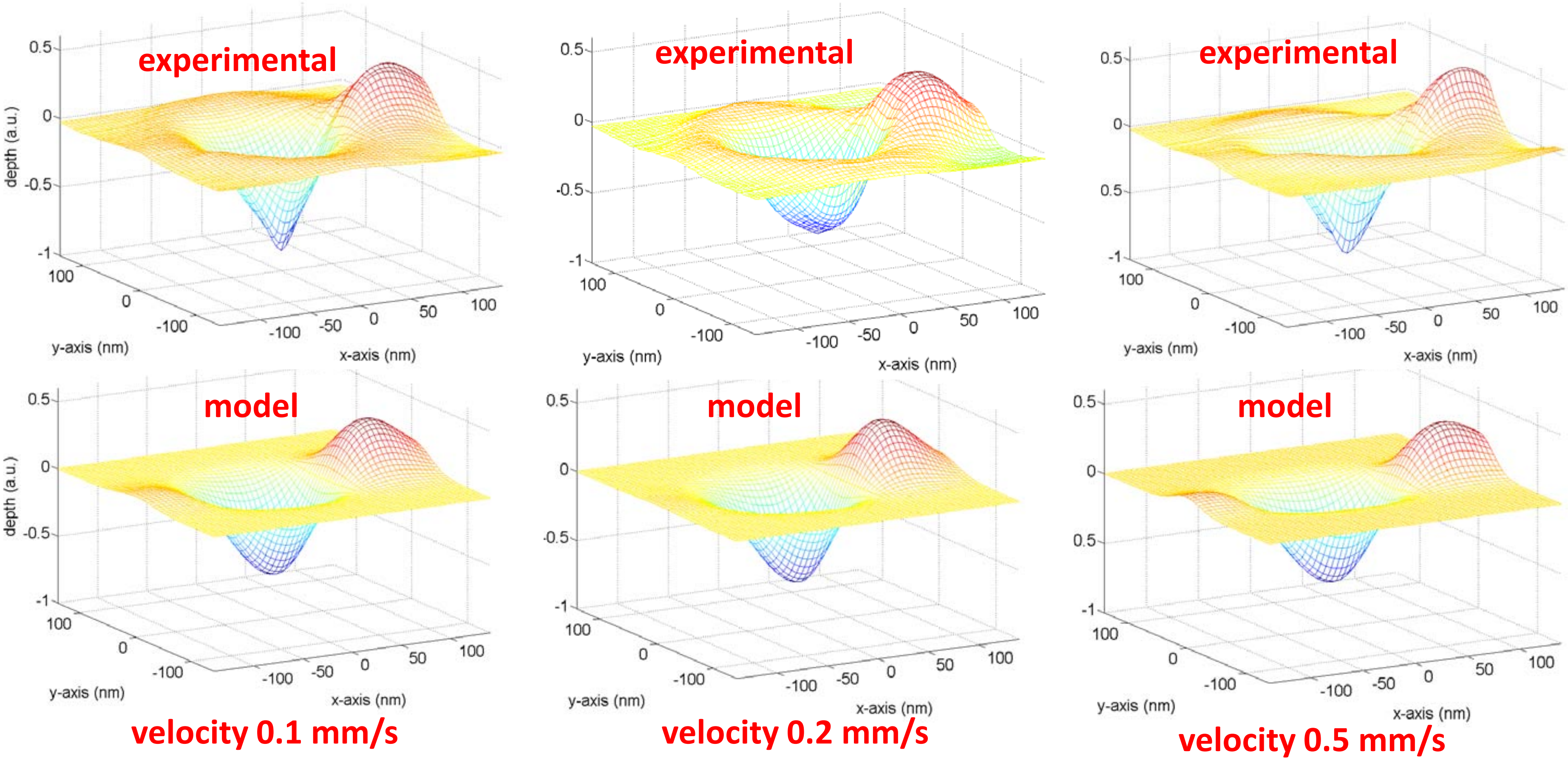


x/y scan step during imaging: **5 nm**

scan direction during formation process

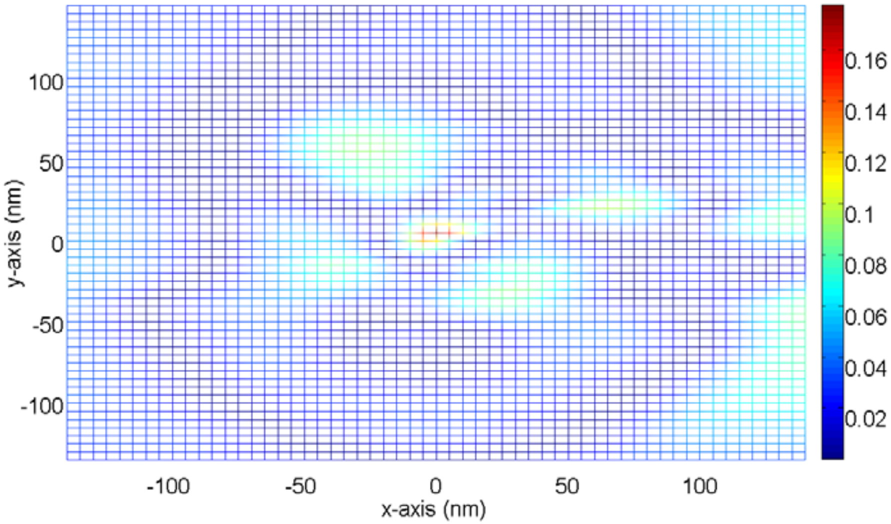
- ❑ 2-D cross correlation of the imaged surface with a basic pulse → detection of nano-indentation centers
- ❑ Averaging for extraction of the mean experimental indentation per scan velocity

Model fitting to experimental average indentations

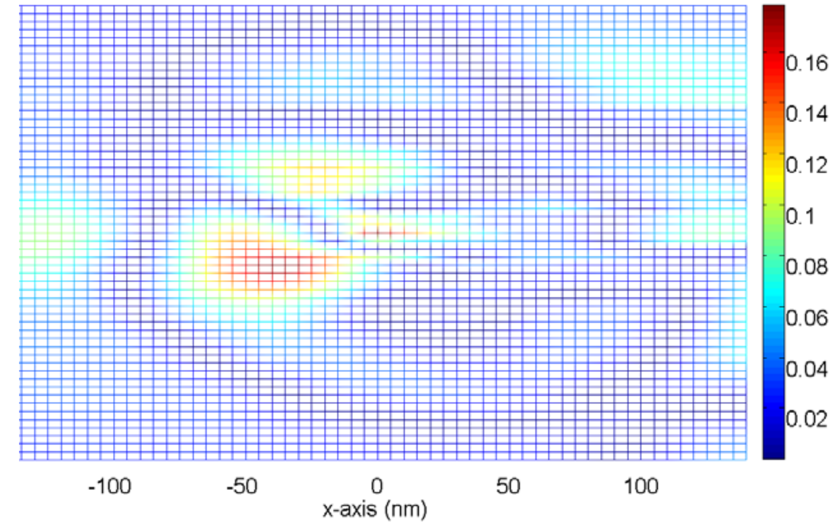


- ❑ Find ***p*** such that ***S(x,y)*** best fits the average experimental indentation for each scan velocity.
- ❑ The optimal solution is obtained using non-linear least squares.

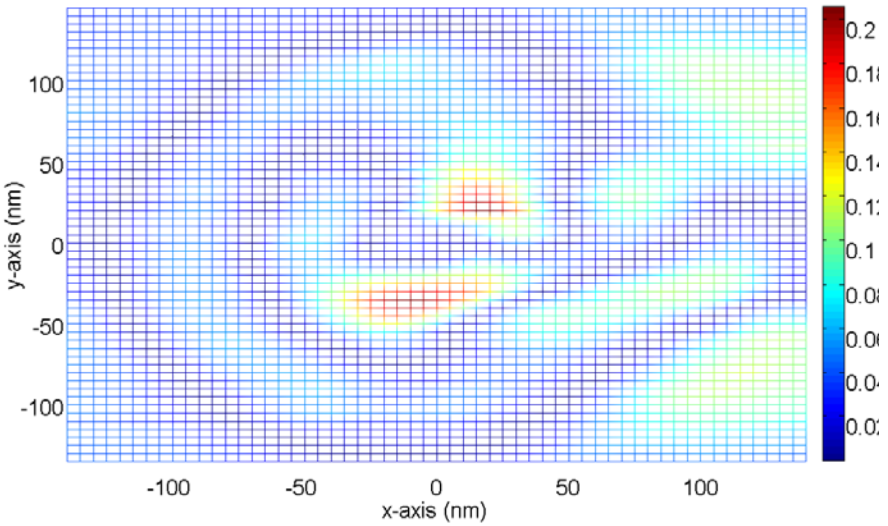
velocity 0.1 mm/s

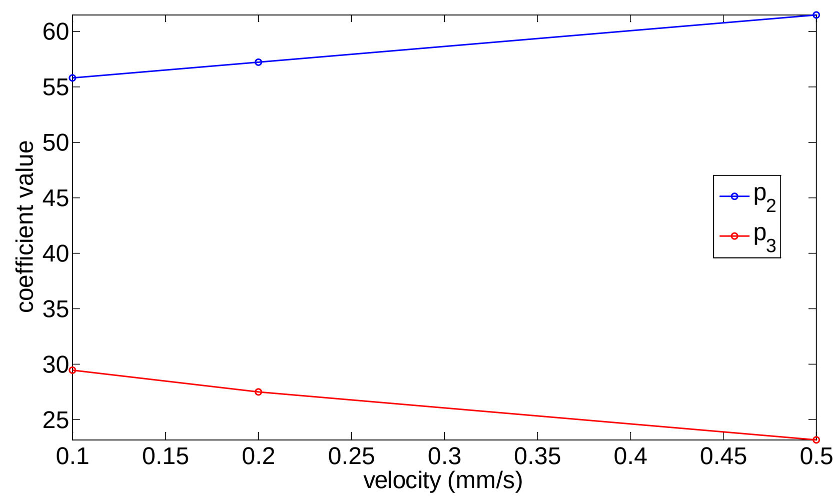


velocity 0.5 mm/s



velocity 0.2 mm/s





Conclusions

- An analytical 3-D model of nano-indentations engraved on a thin polymer film has been derived.
- The model was based on experimental data obtained using an AFM-based setup equipped with thermomechanical cantilevers .
- The model captures well the asymmetry and shape of the actual indentation and adapts well when the velocity of the scanner during the formation process varies.
- The error between the two surfaces in terms of euclidean distance is below 20% of the maximum indentation depth.