P14 – Micromechanics of Thin Films of Elastomeric Polypropylene

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Elastomeric polypropylene consists of lamellar crystals embedded in an amorphous matrix. The arrangement, distribution, and connectivity of these crystals are important factors which determine the mechanical properties of the polymer. A typical morphology of the material consists of long mother lamellae with short branches of epitaxially grown daughter lamellae. The angle formed between mother and daughter lamellae is 80°[1-4]. These epitaxial branches are very rigid connections and do not change on straining up to strains of 40%. The mechanical stability of these branches is similar to that of the lamellae themselves.

We developed a sample preparation technique and a micro stretching device, that allow imaging the deformations of individual crystalline lamellae at increasing and decreasing degrees of strain of ~ 1 µm thick films with scanning force microscopy (SFM) [1a)]. Besides of observing the changes in shape, orientation, and morphology of crystalline regions we are able to measure forces during stepwise stretching and relaxing by an integrated silicon force sensor.

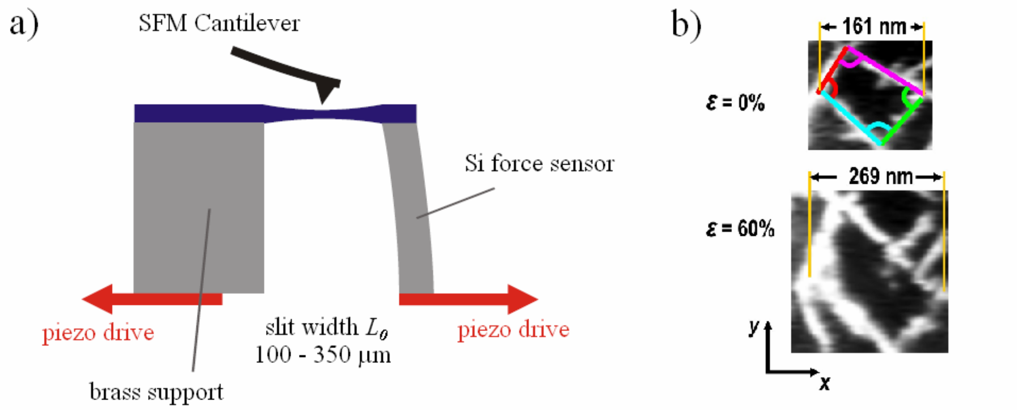

Figure 1: a) Schematic of the micro stretching device. b) SFM phase images of crystalline lamellae in elastomeric polypropylene in a 1 µm thick film at a macroscopic strain of ε = 0% and 60% in y-direction. Epitaxial grown branches elongate during straining, which leads to a lateral expansion of the cluster due to constant contact angles and width of the lamellae.

During a strain experiment of an elastomeric polypropylene with 12% crystallinity polymerized by metallocene catalysis we observed an unexpected expansion perpendicular to strain direction of some epitially grown crystalline lamellae on the 100-nm-scale, similar to auxeticity [5-7].

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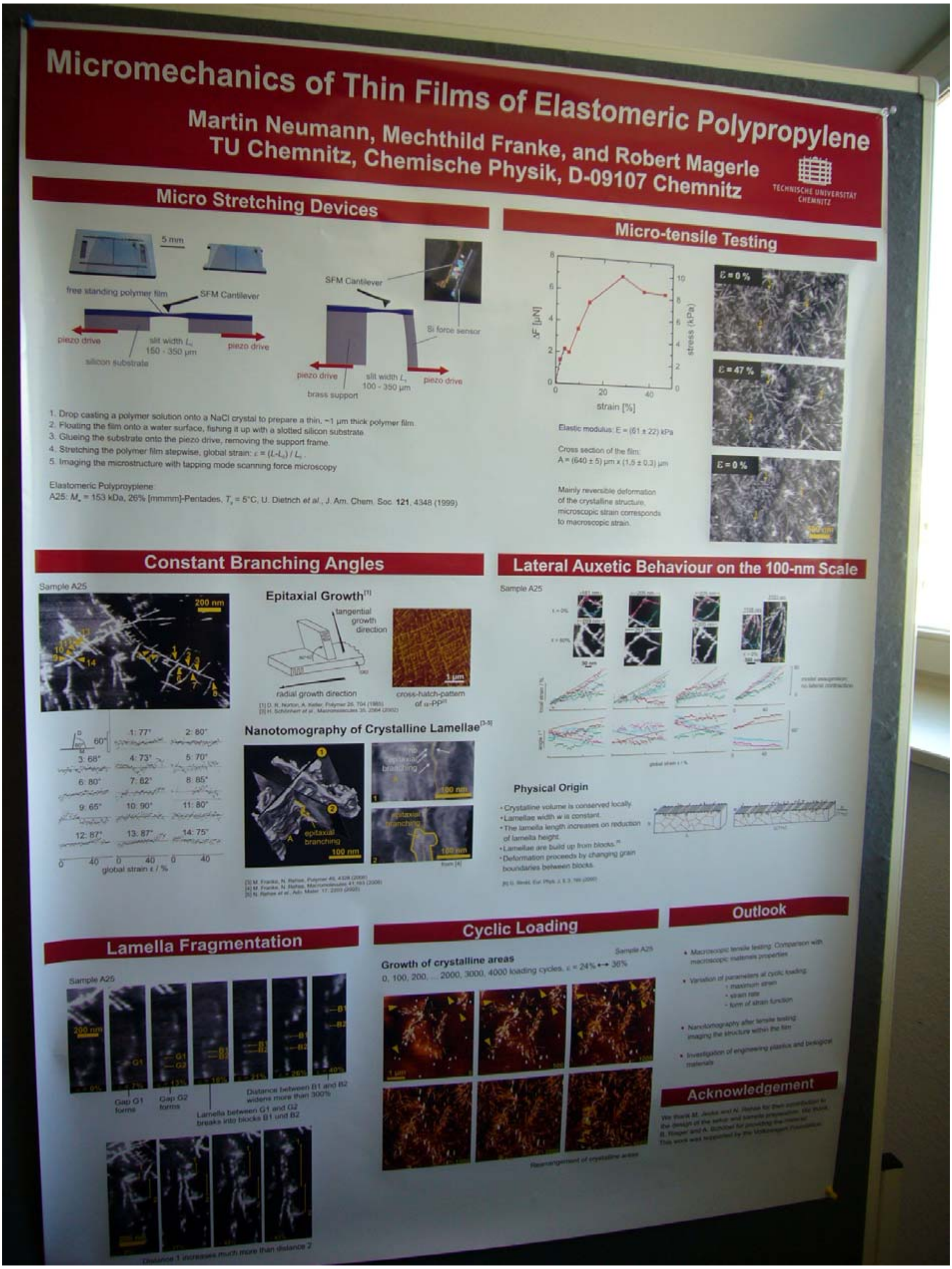

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Micro Stretching Devices

1. Drop casting a polymer solution onto a NaCl crystal to prepare a thin, ~1 µm thick polymer film.
2. Floating the film onto a water surface, fishing it up with a slotted silicon substrate.
3. Glueing the substrate onto the piezo drive, removing the support frame.
4. Stretching the polymer film stepwise, global strain: $\varepsilon = (L-L_0) / L_0$.
5. Imaging the microstructure with tapping mode scanning force microscopy

Elastomeric Polyproypiene:
A25: M_w = 153 kDa, 26% [mmmm]-Pentades, T_g = 5°C, U. Dietrich *et al.*, J. Am. Chem. Soc. **121**, 4348 (1999)

Micro-tensile Testing

Elastic modulus: E = (61 ± 22) kPa

Cross section of the film:
A = (640 ± 5) µm x (1.5 ± 0.3) µm

Mainly reversible deformation of the crystalline structure, microscopic strain corresponds to macroscopic strain.

Constant Branching Angles

Sample A25

Epitaxial Growth[1]

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Nanotomography of Crystalline Lamellae[3-5]

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Lateral Auxetic Behaviour on the 100-nm Scale

Sample A25

Physical Origin

- Crystalline volume is conserved locally.
- Lamellae width w is constant.
- The lamella length increases on reduction of lamella height.
- Lamellae are build up from blocks.[6]
- Deformation proceeds by changing grain boundaries between blocks.

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Lamella Fragmentation

Sample A25

Distance 1 increases much more than distance 2

Cyclic Loading

Sample A25

Growth of crystalline areas
0, 100, 200, ... 2000, 3000, 4000 loading cycles, ε = 24% ⟷ 36%

Rearrangement of crystalline areas

Outlook

- Macroscopic tensile testing: Comparison with macroscopic materials properties
- Variation of parameters at cyclic loading
  - maximum strain
  - strain rate
  - form of strain function
- Nanotomography after tensile testing: imaging the structure within the film
- Investigation of engineering plastics and biological materials

Acknowledgement

We thank M. [illegible] and N. Rehse for their contribution to the design of the setup and sample preparation. We thank B. Rieger and A. [illegible] for providing the material. This work was supported by the Volkswagen Foundation.