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Title: Laser Micromachining for Polymer Surface Topography Design

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Author Questionnaire

1. Microscopy: Does your protocol require the use of a dissecting or stereomicroscope for performing a complex dissection, microinjection technique, or something similar? **No**

2. Software: Does the part of your protocol being filmed include step-by-step descriptions of software usage? **Yes**

3. Filming location: Will the filming need to take place in multiple locations? **Yes**

1.1 km

Current Protocol Length
Number of Steps: 08
Number of Shots: 28

Introduction

Videographer: Obtain headshots for all authors available at the filming location.

1.1. **Gašper Kokot:** We are researching new applications and capabilities of laser micromachining. We are working on determining the conditions and parameter space for processing different types of materials.

1.1.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera.

What are the current experimental challenges?

1.2. **Gašper Kokot:** Currently, our main focus is surfaces of polymers, in particular magnetoactive elastomers, that can be difficult to process using other techniques, due to their stickiness.

1.2.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera *Suggested B-roll: Figure 3*

What advantage does your protocol offer compared to other techniques?

1.3. **Gašper Kokot:** Our protocol describes a maskless structuring of surfaces, which enables rapid prototyping. It also allows for the creation of slanted structures that are not possible with other techniques.

1.3.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera

Videographer: Obtain headshots for all authors available at the filming location.

Protocol

2. Laser Micromachining

Demonstrators: Gaia Kravanja and Izidor Straus

2.1. To begin, place the cured magnetoactive elastomer sample on the working area of the scanning head **[1],** ensuring it is positioned in the focal plane and tilted to the preselected angle **[2]**. Using the laser control software, design the scanning trajectory by tracing the area where material should be removed **[3]**.

2.1.1. WIDE: Talent positioning the cured magnetoactive elastomer sample on the scanning head.

2.1.2. Talent adjusting for focus and tilt.

2.1.3. SCREEN: 68126_screenshot_2.mp4: 01:22-01:42.

2.2. For optical microscopy, clean the sample using pressurized nitrogen gas to gently blow away any dust or debris particles **[1]**. Place the cleaned sample on the microscope table and switch on the reflective microscopy light source **[2]**. Select the 10X objective lens to measure lateral dimensions such as the pitch between lamellae **[3]**. Then, switch to the 40X objective lens to capture data on the height of the structures **[4]**.

2.2.1. Talent using a nitrogen gas gun to clean the sample surface.

2.2.2. Talent placing the sample on the microscope stage and turning on the reflective light source.

2.2.3. SCREEN: 68126_screenshot_2.mp4: 00:07-00:20

2.2.4. Talent rotating the objective turret to switch to the 40X lens and focusing on the sample.

2.3. Then, open the field aperture on the microscope to reduce the depth of the field **[1]**. Adjust the height of the micrometer stage **[2]** to focus on the top surface of the structures **[3]** and record the reading on the micrometer screw **[4]**.

2.3.1. Talent adjusting the field aperture to shallow the depth of field.

2.3.2. Talent adjusting the height of the micrometer stage

2.3.3. SCREEN: 68126_screenshot_2.mp4: 00:30-00:40, 01:02-01:07

2.3.4. Talent noting the micrometer screw reading.

2.4. Afterward, gradually raise the stage by turning the micrometer screw **[1]** until the substrate surface comes into focus **[2],** then record this new value **[3-TXT]**.

2.4.1. Talent slowly turning the micrometer screw to raise the stage.

2.4.2. Shot of the focused substrate.

2.4.3. Talent noting the reading. **TXT: Calculate height by subtracting the two micrometer readings**

3. Scanning Electron Microscopy of MAE Sheets

Demonstrator: Izidor Straus

3.1. Wear gloves and, using a scalpel, cut the samples to match the size of the scanning electron microscopy sample holder pins **[1]**. With the help of plastic tweezers, attach the trimmed samples to the pins, taking care not to damage them **[3]**. Then, clean the mounted samples with pressurized nitrogen gas to remove any dust or debris **[4]**. Place the pins with the attached samples into the stage and record their positions **[5]**.

3.1.1. Talent cutting a sample to size using a scalpel.

3.1.2. Talent using plastic tweezers to carefully place the trimmed sample onto an SEM pin.

3.1.3. Talent cleaning the mounted sample with pressurized nitrogen gas.

3.1.4. Talent inserting the pins into the SEM stage and noting down the sample positions.

3.2. Next, to perform backscattered electron measurements, first evacuate air from the vacuum chamber to reach a high vacuum state **[1]**. Capture an optical navigation image of the samples and use it to guide the stage, positioning the sample of interest at the correct distance from the detector edge **[2]**. Activate the electron beam and display the image from the concentric backscatter detector **[3]**. To set the beam parameters, select a 30-kilovolt accelerating voltage, a spot size of 4.0, and a dwell time of 5 microseconds **[4]**.

3.2.1. Talent initiating vacuum pumping on the SEM to achieve high vacuum.

3.2.2. SCREEN: 68126_screenshot_3.mp4: 00:00-00:26, 00:40-00:52

3.2.3. SCREEN: 68126_screenshot_4.mp4: 00:23-00:25, 00:56-01:10

3.2.4. SCREEN: 68126_screenshot_4.mp4: 00:00-00:20

3.3. For secondary electron measurements, adjust the chamber to a low vacuum of 0.70

millibar **[1]**. Move the samples to a working distance of approximately 3.5 millimeters **[2]**. Then, switch on the electron beam and view the image captured by the low-vacuum secondary electron detector **[3]**.

3.3.1. SCREEN: 68126_screenshot_5.mp4: 00:00-00:15

3.3.2. SCREEN: 68126_screenshot_5.mp4: 00:18-00:34

3.3.3. SCREEN: 68126_screenshot_5.mp4: 01:17-01:40

3.4. Next, attach a piece of double-sided adhesive tape to the center of the sample holder between the poles of the electromagnet **[1]**. Place the sample on the adhesive tape, ensuring it is centered between the poles **[2]**. While capturing images, apply a 3.2 ampere direct current to the electromagnet to generate a homogeneous magnetic field of approximately 340 millitesla in the 20-millimeter pole gap **[3]**.

3.4.1. Talent attaching a strip of double-sided adhesive tape to the sample holder between the electromagnet poles.

3.4.2. Talent carefully placing the sample atop the adhesive tape in the central position.

3.4.3. SCREEN: 68126_screenshot_6.mp4: 00:00-00:40

Results

4. Results

4.1. Optical microscopy confirmed the defect-free pattern of the magnetoactive elastomer surface, with clear lateral structuring and focus adjustments validating vertical profile visibility **[1].** Scanning electron microscopy revealed that the structured pillars have a coarse surface texture with distinct micro-particles embedded throughout the side profile **[2].**

4.1.1. LAB MEDIA: Figure 3A. *Video editor: Highlight the wide view showing evenly spaced vertical ridges with no visible defects*.

4.1.2. LAB MEDIA: Figure 3B. *Video editor: Emphasize the side profile image where the vertical structure is covered in scattered bright micro-particles.*

4.2. Secondary electron imaging revealed a rugged and irregular polymer surface structure at high resolution **[1].**

4.2.1. LAB MEDIA: Figure 3B. *Video editor: Highlight the lower image showing wavy, irregular surface patterns in grayscale*.

4.3. Magnetic manipulation resulted in visible tilting of the microstructures over time, as observed in the side views under different field exposures **[1].**

4.3.1. LAB MEDIA: Figure 4. *Video editor: Show the side view images with all protrusions.*

Pronunciation Guide

1. Elastomer

- **Pronunciation Link:** https://www.merriam-webster.com/dictionary/elastomer Merriam-Webster
- **IPA (AmE):** /ɪˈlæstəmɚ/
- **Phonetic Spelling:** i-LAST-uh-mer

2. Lamellae

- **Pronunciation Link:** https://www.merriam-webster.com/dictionary/lamellae Merriam-Webster
- **IPA (AmE):** /mə-ˈlel-ē/ *(this reflects Merriam-Webster's typical pronunciation pattern for plural forms ending in "-ae")*
- **Phonetic Spelling:** muh-LEL-ee

3. Micrometer

- **Pronunciation Link:** https://www.merriam-webster.com/dictionary/micrometer Merriam-Webster
- **IPA (AmE):** /mī-ˈkräm-ət-ər/ or /ˈmī-krō-ˌmēt-ər/ *(multiple variant pronunciations)*
- **Phonetic Spelling:** my-KRAH-muh-ter or MY-kroh-mee-ter

4. Electromagnet

- **Pronunciation Link:** https://www.merriam-webster.com/dictionary/electromagnet Merriam-Webster
- **IPA (AmE):** /i-ˌlek-trō-ˈmag-nət/
- **Phonetic Spelling:** ee-LEK-troh-MAG-nut

5. Secondary electron *(two-word technical term)*

- **Pronunciation Link for "secondary electron":** https://www.merriam-webster.com/dictionary/secondary%20electron Merriam-Webster
- **IPA (AmE):** /ˈsɛkənˌdɛri i-ˈlɛk-trän/
- **Phonetic Spelling:** SEK-un-der-ee ee-LEK-trahn

6. Backscatter(ed)

- **Pronunciation Link:** https://www.merriam-webster.com/dictionary/backscatter Merriam-Webster
- **IPA (AmE):** /ˈbak-ˌskat-ər/ (backscatter), /back-ˈskatˌərd/ (backscattered)
- **Phonetic Spelling:** BACK-skat-er (backscatter) / back-SKAT-urd (backscattered)

7. Vacuum

- **Pronunciation Link:** https://www.merriam-webster.com/dictionary/vacuum Merriam-Webster
- **IPA (AmE):** /ˈvak-yüm/, /-yu̇-əm/, /-yəm/
- **Phonetic Spelling:** VAK-yoom or VAK-yuh-um

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8. Magnetoactive *(not found in Merriam-Webster, but defined in Wiktionary)*

- **Pronunciation Link:** https://en.wiktionary.org/wiki/magnetoactive Wiktionary
- **IPA (estimated, American):** /ˌmæg.nə.toʊ-ˈæk.tɪv/
- **Phonetic Spelling:** mag-NEH-toh-AK-tiv