Master project in nanostencil lithography

Master's thesis

(Section: Microengineering)

Nanostencil lithography is well known for its simple and efficient resist-free nanopatterning [1]. Despite some limitations it enables unique micro and nanopattern made on fragile substrates without the use of 'harsh' process steps typically involved in photo or electron beam lithography. Still, the thin stencil membranes suffer from significant limitations in terms of pattern design flexibility. In the past, two engineering improvements in stencils have shown great improvements: a) corrugated stencil membranes to increase the cross-sectional moment of inertia [2] and b) stencil with small bridges to allow for long and even closed-loop topologies [3]. Both techniques have shown improvements in the use of stencils, but both together have not yet been implemented.
The goal of this master project is to combine corrugated stencils with bridge stencil design and demonstrate the improvement for their use.

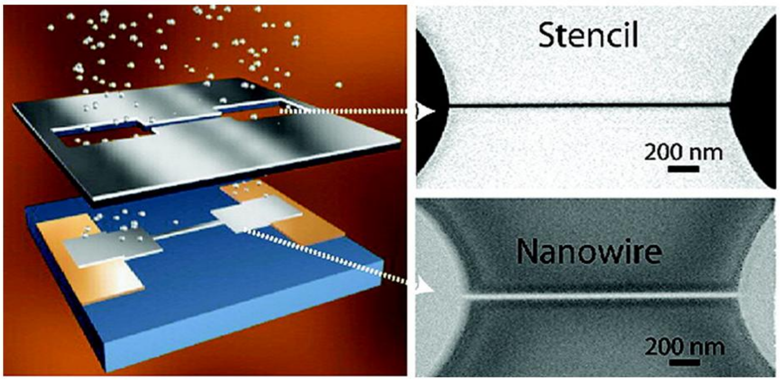

Figure 1 : *schematic showing the principles behind stencil lithography.*

The work involves the following steps (draft plan):

1. Literature study of stencil technology up to date (1 week)
2. Design of test patterns allowing to quantify the stencil performance (1 week)
3. Design of process flow for stencil microfabrication (to be done in CMI) (1 week)
4. CAD of stencil microfabrication process (1 week)
5. (Optional, if needed) FEM for selected design and topology to optimize design parameters (1week)
6. Microfabrication of test stencils in CMI (3 weeks)
7. Testing of stencils using PVD and pattern characterization (2 week)
8. Benchmark various stencils with design/FEM data (2 week)
9. Report and presentation prep, pending tasks

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[1] O. Vazquez-Mena et al. (2015) https://doi.org/10.1016/j.mee.2014.08.003
[2] M.A.F. van den Boogaart et al. (2006) https://doi.org/10.1016/j.sna.2005.08.037
[3] Y.C. Yang et al. (2022) https://doi.org/10.1002/admt.202201119

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Development of an olfactory prosthesis for people suffering from anosmia

Master/Semester project or lab immersion

(Section: Microengineering – Physics – Electric Engineering – Life Science)

Sensory deficits are a major source of handicap in people's lives. Scientists have already developed prostheses and implants for hearing impairments and are developing those for vision. Partial and total loss of smell (hyposmia / anosmia) impacts 20% of the world-wide population with deleterious effects on quality of life. However, we have yet to develop such devices to restore the sense of smell, primarily because scientific knowledge linking artificial systems to human biological olfaction is still lacking. The ROSE project is composed of a European consortium working together to push the limit of artificial olfactory sensations. The project will be held in close collaboration with the European partners and may include travels to meet with them.

At the LMIS1, we are currently investigating new ways of generating sensations in the nasal cavity using different methodologies, such as electrical stimulation. The project is evolving quickly and is highly multidisciplinary, involving aspects of physiology electronics, cleanroom microfabrication and materials science: the focus can be adjusted depending on the student's preferential interests, best knowledge, previous experience and motivation.

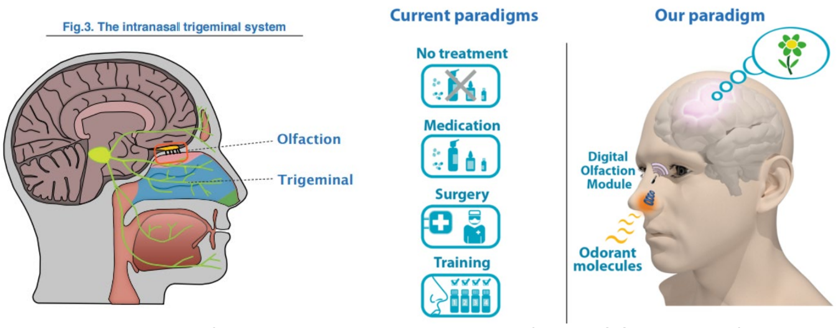

Figure 1 : *(a) schematic showing the olfactory system (b) Paradigm of the ROSE project for the restauration of olfaction in anosmic people*

Possible tasks:

- Cleanroom work
- Microfluidics
- Electronics design
- Experimental characterization
- 3D printing

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Multi-nozzle melt electrowriting (MEW) using microfluidic approaches

Master's thesis

(Section: Computer Science – Materials Science – Microengineering – 3D Printing)

Over the last two decades, additive manufacturing (AM or 3D printing) has been gaining significant attention in tissue engineering and biofabrication research as a versatile class of manufacturing technologies. This primarily stems from its ability to fabricate unique patient-specific designs as well as structures from a wide range of biomaterials.[1] For biomedical applications, high resolution 3D printing techniques, such as melt electrowriting (MEW) have been of interest for their exceptional ability to replicate the fine features and complex microarchitecture of native tissues to mimic both their structure and function.[2] Recently, a dual nozzle setup was demonstrated with a syringe based system and the effects of the electrical field on it studied.[3]

At the LMIS1, we are currently investigating a novel filament-based extrusion system, which has many advantages over the syringe system due to the possibilities in processing a wider variety of polymers.[4] As we have more freedom in nozzle design when using microfabrication, this should prove beneficial for the investigation of dual and multi-nozzle setups. This student project will contribute to the understanding of how the different parameters nozzle spacing, nozzle amount, and nozzle diameter interact and result in a printed fibre. This can allow for more control over the jet and the resulting structures for future applications.
The topic is highly multidisciplinary, involving aspects of engineering, computer and materials science: the focus can be adjusted depending on the student's preferential interests, best knowledge, previous experience and motivation.

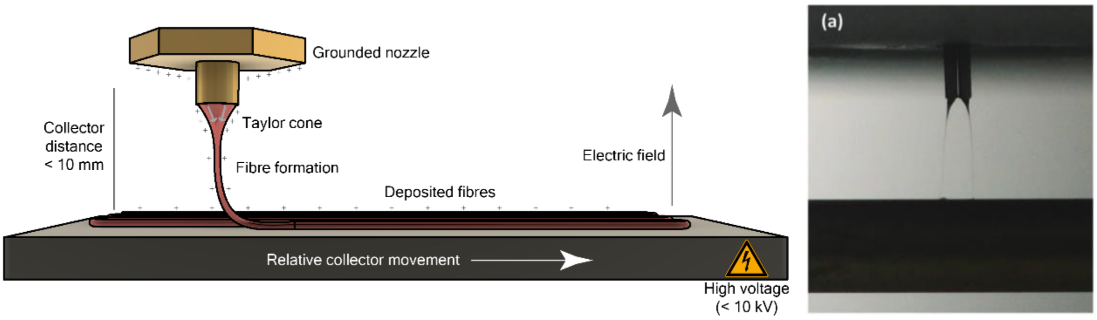

Figure 1 : *(left) schematic showing the principles behind melt electrowriting (MEW), (right) dual nozzle setup in operation, image taken from [3].*

Possible tasks:

- Design and manufacturing of dual and multi nozzle chips in CMi for our printers.
- Design of experiments to print different scaffolds and investigate different nozzle designs.
- Simulation of nozzles and their electrical properties (see [3]).
- SEM characterisation of scaffolds on modern instruments.

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[1] B.P. Chan, K.W. Leong, *Eur Spine J*, **2008**, *17*, 467-479.
[2] J.C. Kade, P.D. Dalton, *Adv Healthcare Mater*, **2021**, *10*, 2001232.
[3] R. Sanchez Diaz, *et al.*, *Macromol. Mater. Eng.*, **2023**, *308*, 220526.
[4] A. Reizabal, *et al.*, *Addit Manuf*, **2023**, *71*, 103604.

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Investigation of melt electrowritten scaffold design on drug delivery

Master's thesis/Semester project

(Section: Biomedical Eng. – Materials Science – Electrical Eng. – 3D Printing)

Over the last two decades, additive manufacturing (3D printing) has been gaining significant attention in tissue engineering and biofabrication research as a versatile class of manufacturing technologies. This primarily stems from its ability to manufacture unique patient-specific designs and structures from a wide range of biomaterials.[1] For biomedical applications, high resolution 3D printing techniques, such as melt electrowriting (MEW) have been used for their exceptional ability to replicate the fine features and complex microarchitecture of native tissues to mimic both their structure and function.[2] To date, MEW research often utilises pressure-driven extrusion methods on custom devices built by individual research groups, processing the most common polymer in MEW poly(caprolactone) (PCL).

At LMIS1, we are currently investigating a novel filament-based extrusion system which has many advantages over the current standard due to the possibilities of processing a wider variety of polymers.[3] A current gap is in the understanding of the influence of the printing geometry on drug uptake and release in aqueous media. This student project will contribute to the understanding of this by printing structures, loading them with (model) drugs and studying their release via spectroscopic methods.
The topic is highly multidisciplinary, involving aspects of engineering, pharmacy, and materials science: the focus can be adjusted depending on the student's preferential interests, best knowledge, previous experience and motivation.

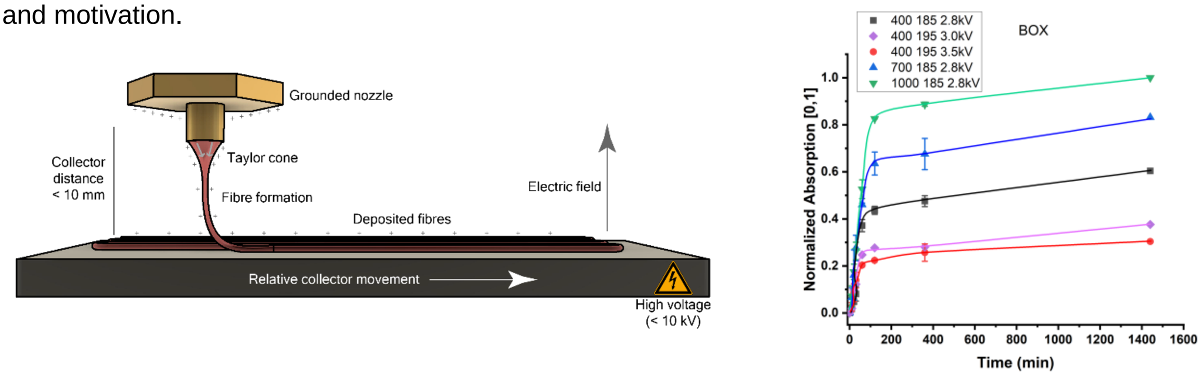

Figure 1 : *(left) schematic showing the principles behind melt electrowriting (MEW), (right) release pattern from preliminary studies.*

Possible tasks:

- Analysis of the influence of geometry and printing design onto the drug release via
    a. Manufacturing of scaffold with different geometries
    b. Loading of scaffolds with (model) drugs (preliminary work already done)
    c. Drug release studies in aqueous solution
    d. Effect of design and drug loading on mechanical properties
- SEM characterisation of finalised scaffolds.

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[2] J.C. Kade, P.D. Dalton, *Adv Healthcare Mater*, **2021**, *10*, 2001232;
[3] A. Reizabal, *et al.*, *Addit Manuf*, **2023**, *71*, 103604.

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Implementation of machine learning (i.e. Bayesian Optimisation) and computer vision for melt electrowriting (MEW)

Master's thesis

(Section: Computer Science – Materials Science – Software Engineering – 3D Printing)

Over the last two decades, additive manufacturing (3D printing) has been gaining significant attention in tissue engineering and biofabrication research as a versatile class of manufacturing technologies. This primarily stems from its ability to fabricate unique patient-specific designs as well as fabricate structures from a wide range of biomaterials.[1] For biomedical applications, high resolution 3D printing techniques, such as melt electrowriting (MEW) have been favoured for their exceptional ability to replicate the fine features and complex microarchitecture of native tissues to mimic both their structure and function.[2] To date MEW research often utilises pressure-driven extrusion methods on custom devices built by individual research groups, processing the most common polymer in MEW poly(caprolactone) (PCL).

At the LMIS1, we are currently investigating a novel filament-based extrusion system, which has many advantages over the current standard due to the possibilities in modification and customisation.[3] A current research gap is in the control of the print on-the-fly, while monitoring it, and reacting to environmental factors. This thesis will contribute to the implementation of a visual system, linked to Bayesian optimisation (BO[4]) for on-the-fly corrections of the print and precision control over the resulting fibres.
The topic is highly multidisciplinary, involving aspects of engineering, computer and materials science: the focus can be adjusted depending on the student's preferential interests, best knowledge, previous experience and motivation. (Fundamental) knowledge of BO is a must, but can be expanded upon with literature study.

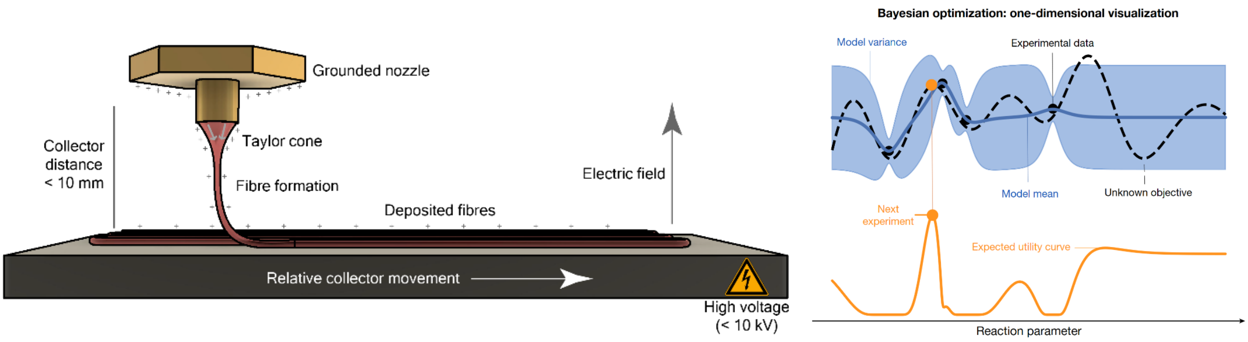

Figure 1 : *(left) schematic showing the principles behind melt electrowriting (MEW), (right) graphical overview of Bayesian optimisation, taken from ref 4.*

Possible tasks:

- Improvement of a computer vision system for the printer (Raspberry pi based)
- Implementation of BO analysis of manufactured fibres (further development of previous study)
- Implementation of on-the-fly adaptation of parameters of MEW (such as extrusion rate, voltage and printing speed……)
- SEM characterisation of finalised scaffolds on modern instruments

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[1] B.P. Chan, K.W. Leong, *Eur Spine J*, **2008**, *17*, 467-479.
[2] J.C. Kade, P.D. Dalton, *Adv Healthcare Mater*, **2021**, *10*, 2001232.
[3] A. Reizabal, *et al.*, *Addit Manuf*, **2023**, *71*, 103604.
[4] B.J. Shields, *et al.*, *Nature*, **2021**, *590*, 89.

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3D printer upgrade to enable successful melt electrowriting of tubular structures with various sizes and geometries

Master/Semester project

(Section: Microengineering, Materials Science, Robotics, Bio Engineering)

Over the last two decades, additive manufacturing (3D printing) has been gaining significant attention in tissue engineering and biofabrication research as a versatile class of manufacturing technologies. This primarily stems from its ability to fabricate unique patient-specific designs as well as fabricate structures from a wide range of biomaterials. For biomedical applications, high resolution 3D printing techniques, such as melt electrowriting (MEW) have been favoured for their exceptional ability to replicate the fine features and complex microarchitecture of native tissues to mimic both their structure and function. To date MEW research often utilises pressure-driven extrusion methods on custom devices built by individual research groups, processing the most common polymer in MEW polycaprolactone (PCL).

At the LMIS1, we are currently investigating a novel filament-based extrusion system for MEW, which has many advantages over the current standard due to the possibilities in processing a wider variety of polymers. The printer has two different collector configurations, flat and tubular (cylindrical) collector, which can be used for printing structures. A current limitation of the tubular system is the availability of a single diameter mandrel (3 mm). This student project will contribute to upgrading the printer and interchangeable upgrades to enable successful printing on mandrels with diameter in range of 1 – 5 mm (cylindrical and polygonal). There will be an additional software component in the project which will aim at designing the codes to enable successful MEW on these mandrels.

The topic is highly multidisciplinary, involving aspects of engineering, computer and materials science: the focus can be adjusted depending on the student's preferential interests, best knowledge, previous experience and motivation.

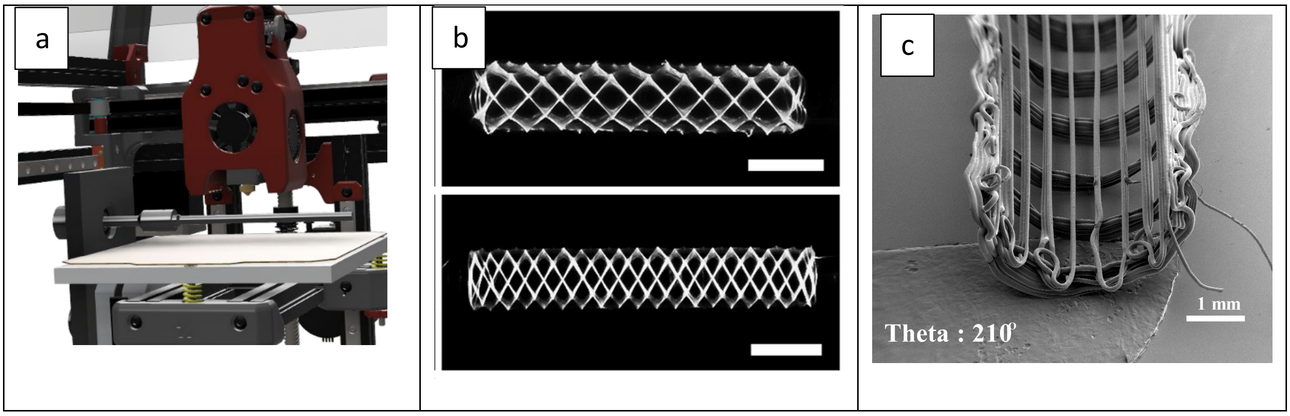

Figure 1. a) Schematic of the idea of tubular collector on MEW printer. b) Sample wrap around tubular designs printed using MEW (2mm scale). c) Theta tubular design for printing using collectors of various diameters.

Possible tasks:

- Modification of the printer for successful processing on various collector sizes/designs
- Software control for printing complex geometries.
- Assessment of mechanical properties of the printed tubes

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Useful reading: Hong et al, Open5x: Accessible 5-axis 3D printing and conformal slicing (https://dl.acm.org/doi/10.1145/3491101.3519782)

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12.06.2024

Fabrication of lipid microneedle by Inkjet printing for prolonged drug delivery

Master/Semester project

(Section: Microengineering – Mechanical Engineering –Bio engineering– Materials Science)

The project focuses on the development of lipid microneedles using inkjet printing for prolonged drug delivery. Microneedles represent a huge advancement in transdermal drug delivery systems, offering a minimally invasive and efficient method for administering medications over extended periods. Co-administration of poorly water-soluble drugs with lipid formulations can enhance the bioavailability of these drugs. Administration of drugs encapsulated lipid formulations can be the one way of achieving this. Recently fabricating the various design of drug-lipid formulations enabled by the development of additive manufacturing techniques. However, fabrication and utilization of lipid microneedle has many challenges due to intrinsic characteristics of lipid. The primary goal of this project is to develop core-shell lipid micro needle using inkjet printing for precise dimensions and drug-loading capacities. The plan involves a detailed investigation of suitable lipid materials, optimization of the inkjet printing parameters, and thorough evaluation of its mechanical and chemical characteristics, microneedles' structural integrity, drug release profiles.

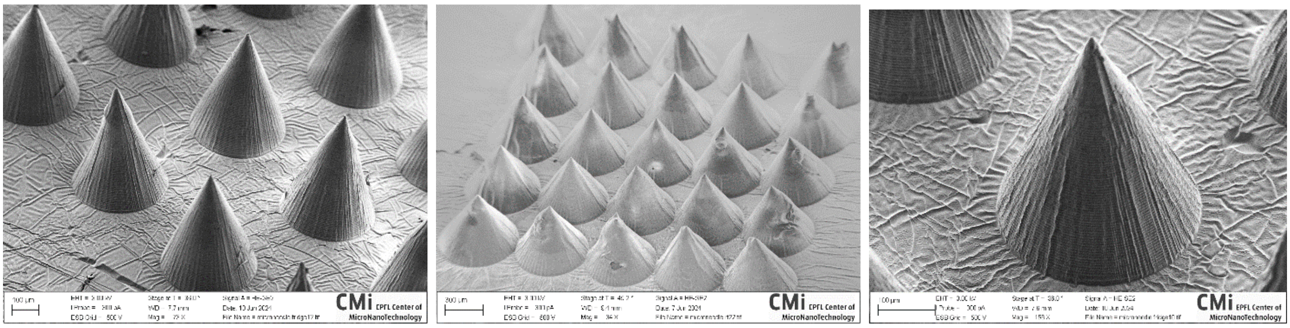

Figure SEM image of fabricated lipid microneedle by IJP

Work description:

- Fabrication of lipid mold in CMI
- Fabrication of lipid micro needle using IJP
- Characterization of microneedle (mechanical and chemical)
- In vitro drug release measurement from microneedle

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Grayscale topography engineering for 2D nanoelectronics

Master thesis / Semester project

(Section: Microengineering – Electrical Engineering - Materials Science)

While nanolithography has historically focused on downscaling, there is now a growing interest in grayscale nanolithography for introducing or enhancing functionality in micro-nanodevices applied for optics and fluidics. **Grayscale thermal scanning probe lithography** (t-SPL) achieves single-digit nanometer spatial resolution and sub-nanometer depth control, but it has limited scalability. We combine t-SPL with **nanoimprint lithography** to replicate high-resolution grayscale nanostructures on large surfaces by step-and-repeat process [1, 2]. For the next generation of nanoelectronics, we use these deterministic grayscale topographies for **strain engineering of 2D materials** as they hold the potential to replace silicon in transistors with sub-10 nm channel lengths.

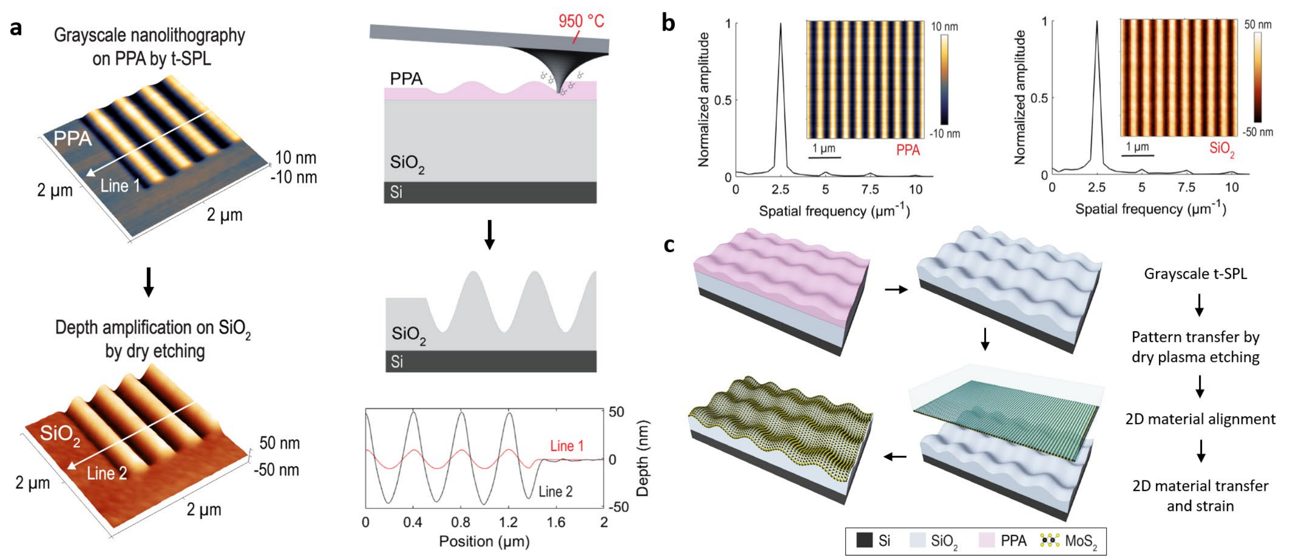

Figure 1: a AFM images and amplitude comparison of a sinusoidal pattern before (Line 1) and after (Line 2) dry etch transfer. **b** Fourier transforms of the measured topographies after t-SPL on PPA and transferred into SiO_2. **c** Fabrication process flow of grayscale dielectric nanostructures for 2D materials strain.

The main tasks in the project will be:

- Grayscale stamp fabrication by combining t-SPL and dry etching
- Nanoimprint lithography and metrology characterization (In case of semester project only)
- 2D material strain characterization

Desired Skills:

- Autonomy
- Knowledge in cleanroom processes is a plus

References:

[1] Howell, Samuel Tobias, et al. "Thermal scanning probe lithography—A review." *Microsystems & nanoengineering* 6.1 (2020): 1-24.

[2] Erbas, B. *et al.* Combining thermal scanning probe lithography and dry etching for grayscale nanopattern amplification. doi:10.1038/s41378-024-00655-y.

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Project updated: 07.06.2024

Designing and Validating Bridges on Stencils

Master/Semester project

(Section: Microengineering – Physics – Materials Science)

Stencil lithography is a resistless micro-fabrication method using a silicon nitride film stencil for pattern deposition or etching.[1] It enables sub-nanometer scale patterns without the need for photoresist or liquid environments. However, challenges include the inability to pattern closed-loop designs due to film detachment, and the risk of stencil curvature or breakage caused by inner stress. Researchers have explored stencil movement during deposition and other approaches to address these issues.

At LMIS1, a new solution was proposed, incorporating auxiliary bridges in stencils. These bridges serve dual purposes: securing the suspended part of the stencil and preventing membrane curvature. By maintaining a specific gap between stencil and substrate, blurring effects during deposition ensure continuous pattern coverage beneath the bridges. Extensive measurements of morphology and electrical properties have validated the effectiveness of the bridge stencil.

The focus of this student project is to optimize the design parameters of bridge stencils. Previous simulations and calculations have revealed interesting phenomena associated with the addition of bridges on the stencil. In this project, students will verify these phenomena in the CMi cleanroom. The tasks will include fabricating bridge stencils with varying parameters, measuring stencil bending, and assessing the profile of deposited patterns through the stencil. These measurements will evaluate the impact of different bridge configurations. The ultimate goal is to develop guidelines for an automated design tool for bridge stencils.

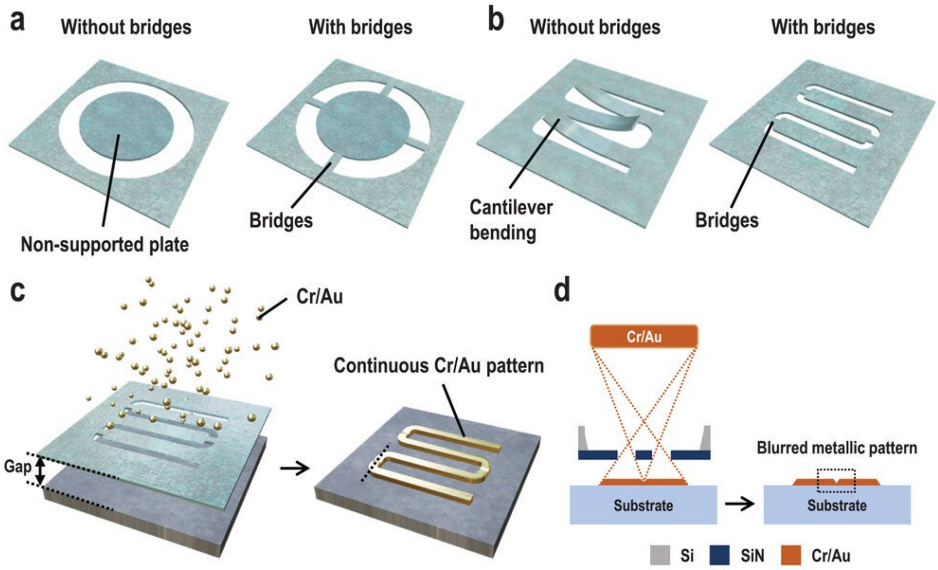

Figure 1 : *The concept of bridge stencils and the blurring effect. a,b) Schematic drawings showing the use of bridges for a) realizing unfeasible geometries on stencils (e.g., close-loop circular apertures), and b) suppressing the bending of cantilevers for meandering apertures. c,d) Schematic drawing showing the beneficial use of the blurring effect. [2]*

Possible tasks:

- Fabrication of bridge stencils and deposition through it
- Measurement of bending of bridge stencil, and profile of deposited patterns
- Verifying the simulation and calculation result, and concluding the concept for designing bridge stencils

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[1] O. Vazquez-Mena et al, vol. 132, pp. 236–254, Jan. 2015.
[2] Y.-C. Sun et al, *Adv. Mater. Technol.*, vol. n/a, no. n/a, p. 2201119.

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Multi-material droplet generation and solidification via microfluidics

Semester Project

(Section: Material Science – Microengineering)

Droplet microfluidics is a technology used to encapsulate fluids, cells, and other materials into microscale droplets.[1] In this project, droplet microfluidics is employed to generate microdroplets of diverse materials, which can then be solidified into microbeads and assembled to construct three-dimensional (3D) objects. This approach enables the conceptualization of a novel 3D printing process based on the voxel-by-voxel assembly of materials with contrasting properties. Recent advancements have been made in developing printheads capable of producing parts with multi-material compositions on a voxel-by-voxel basis.[2,3] However, current techniques remain limited in combining materials with dissimilar properties. In order to develop a novel microfluidic-based additive manufacturing (AM) technique that can deposit materials with distinct properties, there is a research gap to study the multi-material compatibility in droplet microfluidics.

To obtain functional microbeads with nanoparticle fillings, appropriate ink formulations of surface-treated nanoparticles, monomers, and photoinitiators should be prepared at the first step. Rheology of the inks are characterized with a rheometer. With these inks, droplet production and solidification can be studied using the established droplet microfluidic platform. For example, droplet size and generation frequency can be influenced by droplet contents, such as nanoparticle concentrations. The in-flow polymerized microbeads are characterized using SEM. In the end, microfluidic compartments are designed to assemble droplets or beads into 2D structures. The 2D assembly strategies will set fundamentals for 3D microbead assembly in the future.

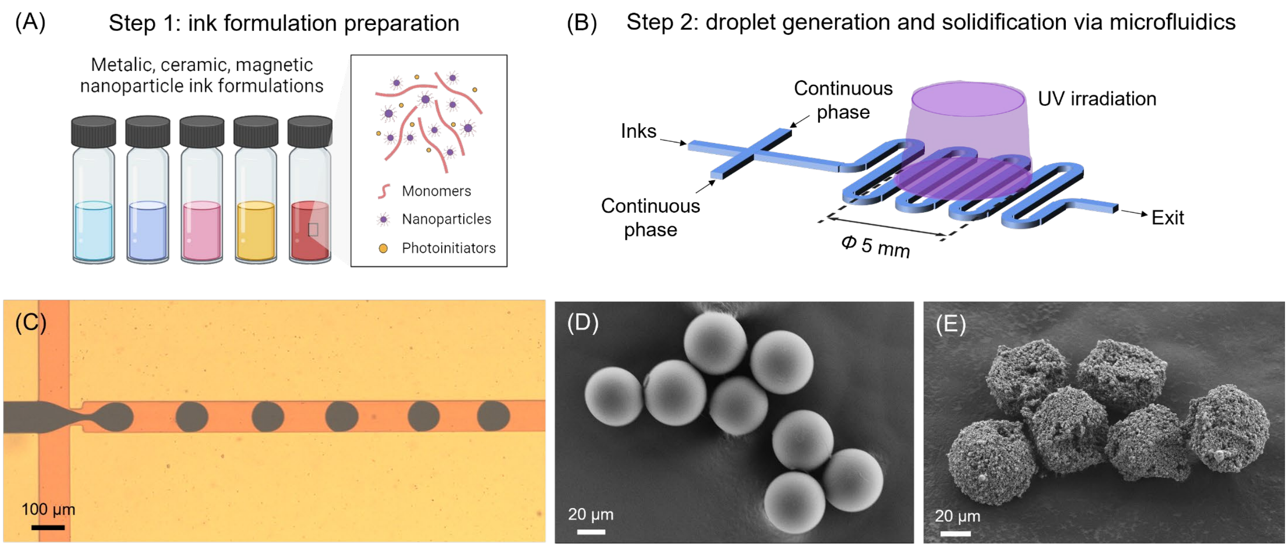

Figure: (A) Preparation of ink formulations. (B) Droplet generation and solidification using a droplet microfluidic platform. (C) Droplets containing silver nanoparticles were formed at a flow-focusing junction in an aqueous continuous flow. An SEM image of UV polymerized microbeads made of (D) PEGDA250 and (E) PEGDA250 with 27 wt% silver nanoparticles.

Possible tasks:

a) Polymerizable ink preparation and rheology (viscosity or viscoelasticity) characterization.
b) Droplet generation and solidification with different droplet contents such as nanoparticle concentration.
c) Droplets or beads 2D assembly using microfluidic compartment designs.

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[1] Zhang, *et al. Trends in Biotechnology* (2023).
[2] Skylar-Scott, *et al. Nature* 575.7782 (2019): 330-335.
[3] Buchner, *et al. Nature* 623.7987 (2023): 522-530.

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In-air droplet generation and solidification via microfluidics

Semester Project

(Section: Material Science – Microengineering)

Droplet microfluidics is a technology used to encapsulate fluids, cells, and other materials into microscale droplets.[1] In this project, droplet microfluidics is employed to generate microdroplets of diverse materials, which can then be solidified into microbeads and assembled to construct three-dimensional (3D) objects. This approach enables the conceptualization of a novel 3D printing process based on the voxel-by-voxel assembly of materials with contrasting properties. In conventional water-oil droplet microfluidics, a large fraction of the flow is from the liquid carrier which is unfavourable to be deposited on 3D printing substrate. One of the strategies is to replace the liquid carrier with air flow to form droplets.[2] However, there is a research gap on studying the in-air droplet generation and polymerization.

Using a step emulsification microfluidic device, water droplets can be controllably generated in air flow. Now, the next step is to form droplets in air flow using low-viscosity acrylate or acrylate containing nanoparticles as the dispersed phase. The droplet size and generation frequency need to be characterized while adjusting the flow rates of two phases. The effect of microfluidic junction geometries on the droplet generation is also expected. Besides, the advancing speed of droplets carried by the air flow is crucial to measure when considering the sequential polymerization step. To gain more time for polymerization in air flow, a new channel design will be explored to slow down the droplet movement in the microfluidic channel. This in-air droplet generation and polymerization study will advance the project to bead ejection and 3D assembly in the future.

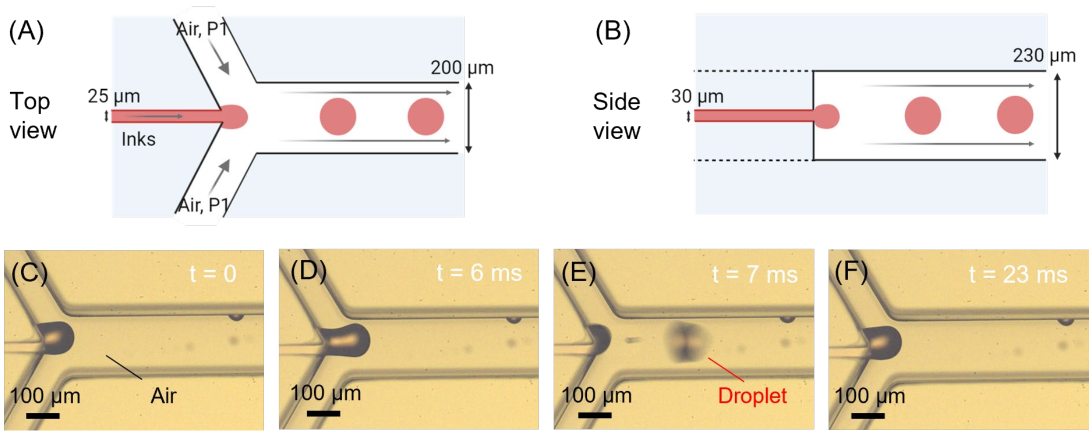

Figure: (A, B) Schematics of step emulsification microfluidic junction. (C-F) Timelapses of generation of a water droplet in air flow using the step emulsification microfluidic junction made of PDMS.

Possible tasks:

a) Acrylate droplet generation in air flow using a step emulsification microfluidic junction.
b) Characterization of the dependence of droplet size, generation frequency, and dispersity on flow rates and channel geometries.
c) Droplet polymerization characterization with or without an air evacuation channel design.

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[1] Zhang, *et al. Trends in Biotechnology* (2023).
[2] Takagi, *et al. Microfluidics and Nanofluidics* 25.9 (2021): 74.

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Characterization of NbTi Superconducting Thin Film Non-Linear Devices for Quantum Superconducting Circuits

Master/Semester project

(Section: Microengineering – Physics – Electronic Engineering)

Nowadays, quantum technologies based on superconducting materials are becoming of primary importance for the development of new computational paradigms, as well as for designing a new generation of ultra-sensitive cryogenic sensors. The possibility to exploit nonlinear effects, such as the Josephson one, is crucial for the implementation of detection mechanisms relying on the quantization of physical parameters, like, for instance, the magnetic flux in Superconducting Quantum Interference Devices (SQUIDs) [1] and the frequency-to-voltage conversion based on the Shapiro steps phenomenon [2].

At LMIS1, we are currently investigating new possibilities of realizing alternatives to standard SIS or SNS Josephson junctions at cryogenic environments (T < 90 K). We are developing new ways of inducing the Josephson junction behavior on a localized region of the superconducting circuits by simple fabrication methods. The strategy consists of exploiting some of the quantum properties of the superconductors at the micro-nano-scale.

This student project will contribute to investigate the electronic transport of specific structure realized in superconducting NbTi thin films, eventually demonstrating the possibility to exploit them for realizing more complex structures based on nonlinear Josephson junctions (i.e. SQUIDs and Shapiro steps). The topic is highly multidisciplinary, involving aspects of condensed matter and low temperature physics, as well as DC/RF electronics design and test: the focus can be adjusted depending on the student's preferential interests, best knowledge, previous experience and motivation.

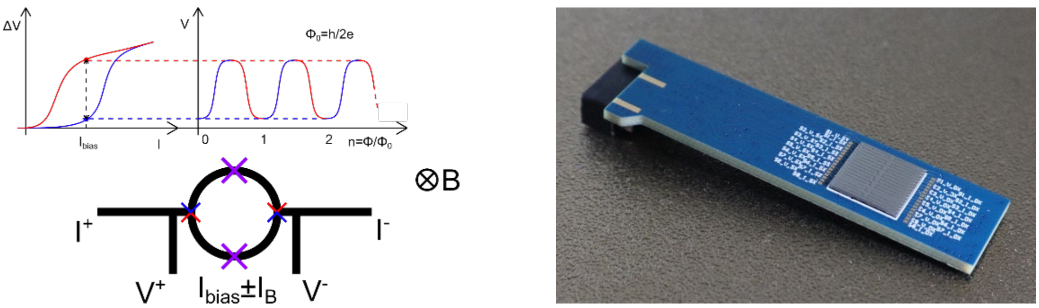

Figure 1 : *(a) schematic showing the working principle of a SQUID magnetometer; (b) Photograph of a chip containing superconducting structures in NbTi to be characterized in cryogenic environments (< 10 K).*

Possible tasks:

- Implementation of measurement apparatuses for cryogenic DC/RF testing
- Cryogenic characterization of NbTi thin film structures, either in liquid He or in a dry cryomagnet:
    - Temperature or magnetically induced effects in DC structures or RF resonators;
    - Sub-uT magnetic field detection based on our alternative SQUIDs;
    - Frequency-to-voltage conversion based on Shapiro steps phenomenon.

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[1] F. Qu et al. (2012) Scientific Reports 2:339, https://doi.org/10.1038/srep00339
[2] X. Bi et al., (2024) Quantum Frontiers 3:6, https://doi.org/10.1007/s44214-024-00053-5

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