MICRO-724 Paper review assignment

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Enabling chemically amplified resists towards tight pitch EUV patterning by directed self-assembly

L. Vastraete et al.

Short description of topic and relevance for MEMS/NEMS:

The article mainly discussed the combination of two techniques, the direct self-assembly (DSA) which uses the nature of some molecules to assemble on guided patterns. And the extreme ultraviolet (EUV) lithography with chemically amplified resist (CAR) which can achieve high resolution patterning but also suffers from several challenges such as resolution scaling and low pattern variability.
The methods of using EUV and DSA are combined for the nanoscale patterning. Compared to pure EUV lithography, the combination can result in reduction in line width roughness,improvement in pattern placement accuracy and uniformity.
From a MEMS/NEMS perspective, the technique is capable of patterning structures in the 10nm range with reliability and reproducibility.

Key (3-5) take away messages from paper; what outlook do authors provide where the field may go next?

The paper presents that the underlying material plays an important role in the pattern quality, and demonstrated that the stack of SiCN/amorphous carbon bilayer that improves the patterning line wiggling behaviour. The high-chi block copolymers improve the line width roughness, and also improves the uniformity and placement accuracy on the contact holes array. The paper only shows patterning of simple line/space and hexagonal hole arrays, more complex shapes should be studied to see if the method is also applicable. The author mentioned that also more work is needed for understanding the origin of the line edge roughness during the pattern transfer.

Year of review paper: are there any newer review paper published

The paper was published in 2025.

Quality of review paper; did authors make original content e.g. figures/tables to compile data from literature?

This paper is not a review paper, it focuses on demonstrating the material stack optimization, block copolymer selection and process parameter tuning for tight pitch nanoscale patterning.

Anything else relevant

The other paper : Mitigating stochastics in EUV lithography by directed self-assembly is on the same topic while stressing more on the random stochastic defects and using the DSA method to improve the patterning.

MicroLEDs get in line - Wafer-scale alignment and integration of micro-light-emitting diodes using engineered van der Waals forces

Junsik Hwang et al.

Short description of topic and relevance for MEMS/NEMS:
Although MEMS are not the primary focus, this paper presents concepts that are translatable to MEMS/NEMS. The authors demonstrate a fluidic-assisted self-alignment transfer (FAST) method for µLED chips, using engineered surface roughness and van der Waals forces to achieve rapid, single-face alignment and high-yield bonding to substrates. The method shows the importance of surface engineering and interfacial force control for precise micro/nano-scale device placement. Additionally, it highlights the potential for scalable, batch-level integration of devices, which is directly relevant to MEMS/NEMS manufacturing challenges, such as high-precision assembly of sensors, actuators, or micro-opto-electronic components.

Key (3-5) take away messages from paper; what outlook do authors provide where the field may go next?

- By engineering one smooth, high-adhesion AlN face and one rough, low-adhesion Au face, the FAST method achieves 99.992% alignment yield for over 259,000 µLED chips across 40 trials.

- Controlling the roughness of metal electrodes and the flatness of the AlN layer ensures a strong and predictable adhesion contrast between the two faces.

- The difference in adhesion between the smooth AlN face and rough Au face directs µLED chips to orient correctly on the substrate.

- Solvent properties (type, viscosity, surface tension) and mechanical sweeping with the align bar regulate µLED mobility, accelerate alignment, and help drive out solvent for irreversible bonding.

Outlook of the paper: The authors highlight that while the FAST method successfully demonstrates passive- and active-matrix µLED displays, further developments are needed to scale to higher-resolution and larger displays. This includes optimizing fluidic control parameters, improving alignment yield on interposers, and minimizing chip damage to maintain high power efficiency. Additionally, the GaN-on-silicon technology used has limited optical and electrical performance compared with GaN-on-sapphire, so future work could focus on developing defect-free GaN-on-silicon devices, potentially by integrating two-dimensional materials such as single-crystal graphene as an interlayer to enhance device performance.

Year of review paper: are there any newer review paper published

The paper by Hwang et al. (January 2023) is an experimental research article, not a review. Since its publication, there have been newer developments in μLED transfer and display integration. For example, a recent 2025 study in Advanced Materials (1.6-Inch Transparent Micro-Display with Pixel Circuit Integrated microLED Chip Array by Misalignment-Free Transfer) demonstrates a 1.6-inch transparent micro-display using pixel circuit–integrated microLED chips (PIMLEDs). This work builds on fluidic-assisted self-alignment (FAST) techniques to enable misalignment-free integration of μLEDs with low-temperature polysilicon pixel circuits, achieving uniform optical and electrical properties and demonstrating a fully functional 96 × 96 transparent display.

Quality of review paper; did authors make original content e.g. figures/tables to compile data from literature?

As previously explained, this is not a review but an original content scientific article. In this paper. data is presented in a smooth and understandable way and figures are fairly clear and comprehensive.

Lithography, metrology and nanomanufacturing

J. Alexander Liddle et al.

Short description of topic and relevance for MEMS/NEMS:

In this paper, the authors review top-down and bottom-up nanofabrication techniques from a metrology requirement perspective. They compare a range of approaches including optical step-and-scan, e-beam, STM, nanoimprint, inkjet, particle self-assembly (SA), and diblock copolymer SA considering key properties such as resolution, throughput, cost per unit area, overlay accuracy, defectivity, and the metrology required for process control. The authors highlight SA methods as promising for low-cost, high-throughput applications where higher defect tolerance is acceptable, and they identify optical scatterometry as a metrology technique compatible with both cost and speed requirements of SA methods.

Relevance for MEMS/NEMS: MEMS and photonic devices are highlighted as application spaces where absolute precision, tight tolerances, and scalable patterning are critical even for single level lithography. This makes throughput-aware metrology indispensable for them.

Key (3-5) take away messages from paper; what outlook do authors provide where the field may go next?

1. The primary challenge in semiconductor lithography is not merely creating small features, but producing them uniformly, in close proximity, and with precise placement are requirements that are at least as demanding, if not more so.
2. Line edge roughness (LER) is a significant stochastic contributor to critical dimension (CD) variability in both optical and e-beam lithography. It is closely tied to resist sensitivity and remains difficult to control. The paper discusses the resolution–LER–sensitivity (RLS) trade-off inherent in resist-based lithography, where challenges arise in meeting requirements for CD, CD control, and throughput.
3. The cost of metrology must be aligned with the selling price of the manufactured product, which ultimately determines the choice of metrology technique.
4. Two distinct types of metrologies are required: (i) detailed, in-depth, and relatively slow metrology, which supports process research, development, and identification of critical control factors; and (ii) minimal, high-speed metrology, which enables closed-loop process control in high-throughput manufacturing.

Year of review paper: are there any newer review paper published

This paper was published in 2011.
Many review papers have been published since then; however, the more recent reviews tend to be narrower in scope and more specialized:

1. Sharma E, Rathi R, Misharwal J, Sinhmar B, Kumari S, Dalal J, Kumar A. Evolution in Lithography Techniques: Microlithography to Nanolithography. Nanomaterials (Basel). 2022 Aug 11;12(16):2754. doi: 10.3390/nano12162754. PMID: 36014619; PMCID: PMC9414268.
2. Unno, N.; Mäkelä, T. Thermal Nanoimprint Lithography—A Review of the Process, Mold Fabrication, and Material. Nanomaterials 2023, 13, 2031. https://doi.org/10.3390/nano13142031
3. Cheng X, Liang D, Jiang M, Sha Y, Liu X, Liu J, Cao Q, Shi J. Review of Directed Self-Assembly Material, Processing, and Application in Advanced Lithography and Patterning. Micromachines (Basel). 2025 May 31;16(6):667. doi: 10.3390/mi16060667. PMID: 40572390; PMCID: PMC12194818.
4. Abhijit Biswas, Ilker S. Bayer, Alexandru S. Biris, Tao Wang, Enkeleda Dervishi, Franz Faupel, Advances in top–down and bottom–up surface nanofabrication: Techniques, applications & future prospects, Advances in Colloid and Interface Science, Volume 170, Issues 1–2, 2012, Pages 2-27,

Quality of review paper; did authors make original content e.g. figures/tables to compile data from literature?

This paper is high quality for its time (2011) because:

1. It synthesizes a broad landscape of lithography and metrology options rather than being just a literature listing.
2. The authors have updated some previously published figures and have made new original graphs based on their point of view. They provide original conceptual figures (resolution vs throughput, cost vs throughput, defectivity/complexity plots) that help frame the trade-offs in nanomanufacturing.
3. The review is balanced and critical, emphasizing economic and practical manufacturing considerations rather than only physics/performance.

However, it is now dated, many techniques (e.g., EUV, DSA, NIL) have advanced substantially since 2011.

Thermal scanning probe lithography—a review

Howell et al.

Short description of topic and relevance for MEMS/NEMS:

In this paper, the authors present a thorough review on Thermal Scanning Probe Lithography (t-SPL), an emerging technique employed for the fabrication of micro- and nano-devices with numerous applications in microelectronics, material science, quantum technology and bioengineering. Belonging to the wider group of nanolithography techniques known as Scanning Probe Lithography (SPL), with this approach a heated Atomic Force Microscopy (AFM) tip is employed to induce highly-localized material modifications via thermal energy transfer.

This localized action can be employed to alter the sample surface via material removal, physical or chemical conversion and addition with conventional resolution of 20-50 nm (demonstrated down to sub 10 nm) and possibility to obtain 3D and gray-scale patterning. Its robust setup also retains the conventional capabilities of an AFM system, allowing for real-time in situ imaging of the patterned features and eliminating the need for alignment markers. However, the technique still faces challenges as the low throughput - mainly limited by the mechanical movement of the tip -, tip degradation - due to friction and contamination - and difficult estimation of the actual temperature at the tip-sample contact.

Nowadays, t-SPL is employed in many recent studies:

- Its removal capabilities can be employed to pattern dedicated polymeric resist layers, enabling the subsequent pattern transfer via molding, etching, lift-off or surface activation. This contribution was fundamental in the fabrication of a large range of devices as 3D microfluidic channels or optical microcavities, nanometric electric devices as transistors and memristors and the production of templates and master molds for fast and reproducible pattern transfer.
- The localized material conversion further expands the range of applications of t-SPL for the manipulation of biochemical, organic and magnetic materials. Chemical or protein gradients can be produced on the sample surface, as well as its local oxidation, crystallization, amorphization and even magnetization.
- Material addition can be employed to perform localized deposition of additional layers, or to create local masks for a subsequent etching, molding or surface activation step. This allows for the deposition of delicate organic and polymeric materials otherwise complex to pattern, or localized masks for 2D materials etching or even the creation of freestanding structures.

Key (3-5) take away messages from paper; what outlook do authors provide where the field may go next?

t-SPL is nowadays gaining momentum among the numerous nanolithography techniques thanks to its versatility to operate on different platforms and its innovative capabilities with respect to alternative approaches. In particular, the use of a modified AFM system to deliver efficient and localized heating energy allows for feature patterning with resolution of few tens of nm. Its numerous advantages encompass the patterning of 3D features, grey-scale lithography and the real-time inspection of the patterns through AFM imaging, enabling the mapping of the sample surface for a precise superposition of multiple lithography steps without alignment markers and for the local manipulation of chemical reactions and surface properties of a large range of materials.

Challenges include the potential damage or contamination of the tip, the complex tip-sample dynamics and the relatively low throughput, which still mainly relegates t-SPL systems to research environments. Industrial applications could be obtained with future development of this technique in combination with other writing mechanisms. On one side, the use of multiple parallel cantilevers for simultaneous patterning could speed up the overall exposure of the sample. On the other side, the throughput could be substantially improved with the addition of fast laser writing to pattern the largest features, meanwhile t-SPM would only pattern the areas requiring high resolution.

Year of review paper: are there any newer review paper published

The paper was published in 2020. Since then, t-SPL has been employed in a plethora of contributions, enabling breakthrough achievements in the area of microelectronics, quantum technologies, biochemistry and bioengineering, metasurfaces and optical cavities.

However, only a few review articles have been published on this topic in the last few years, all of them including a more general overview on the various techniques in the SPL family. Two of these articles are

- Fan et al., “Scanning Probe Lithography: State-of-the-are and future perspectives”, Micromachines 2022, 13(2), 228; https://doi.org/10.3390/mi13020228. In this work, together with t-SPL other similar techniques are reviewed, as for instance close-to-atomic-scale SPL, Oxidation SPL, Dip pen SPL, and so on. However, no relevant information on t-SPL is added to the paper here.
- Albisetti et al., “Thermal scanning probe lithography”, Nature Reviews, Methods Primers (2022). In this article, a more comprehensive picture on t-SPL is presented, with specific discussions on its temperature range (up to 1200°C) and heating time (few tens of microseconds), as well as detailed analysis of biomedical, electronic and magnetic applications. An interesting discussion on t-SPL system limitations and reproducibility is added.

Quality of review paper; did authors make original content e.g. figures/tables to compile data from literature?

The review paper provides a highly comprehensive and thorough overview of t-SPL, strongly detailed in the analysis of its advantages and disadvantages and a vast number of references and articles included in the discussion.

Various original figures are included, especially for the introduction and the general discussion on the various available applications of t-SPL. Clear and understandable schematics guide the reader through the explanation of the physical principle of the technique, while the rest of the figures efficiently summarize the state-of-the-art.

Resistless nanofabrication by stencil lithography: A review

Vazquez-Mena et al.

Short description of topic and relevance for MEMS/NEMS:
In stencil lithography (SL), a mask is used to shadow a flux of matter to locally modify a substrate surface. This method bypasses the use of standard photolithography. Those masks typically consist in Si or Si3N4 thin membranes, or in flexible polymer.
The first advantage of SL is bypassing of photoresists, which enables processing of fragile materials that would be damaged by photoresist processing. SL is also relatively easy to implement, and the stencils can be reused in most cases. Lastly, in dynamic stencil lithography, the stencil is moved across the substrate during processing, which allows many novel fabrication pathways. Nevertheless, stencil lithography suffers from significant drawbacks from blurring effects, clogging of the mask and membrane stability.

Key (3-5) take away messages from paper; what outlook do authors provide where the field may go next?

- Stencil lithography has enabled various research on nanoscale patterning and deposition. It allowed the deposition of down to 15nm dots and lines (nanodots and nanowires) in erbium, and sub-100nm full-wafer processing of various other metals, on both rigid and flexible substrates.
- Thanks to its relatively easy combination with many different processing techniques, this method allows the patterning of complex materials as well as deposition on non-conventional substrates. For instance, combined with molecular beam epitaxy, it was used to deposit quantum well islands below 1um. It can also be used with pulsed laser deposition to deposit ferroelectrics and piezoelectrics. Other techniques can also be used to fabricate superconducting structures.
- Due to the fact that it allows patterning without using photoresists, it allows the processing of materials that would be sensitive or incompatible with photoresist processing steps, such as spin and spray coating, and the use of solvents. Therefore, SL can be a good pathway to process organic compounds, as well as to pattern fragile substrates.
- Dynamic stencil deposition is a variation of SL, in which the stencil is moved while the material is being deposited on the substrate. This enables the fabrication of features that would otherwise not be possible to make, such as closed-loops. These features have been fabricated and characterized by combining dynamic SL in ultra-high vacuum with ADMs and scanning tunneling microscopy for in-situ characterization.
- The main challenge faced in SL is the blurring and is caused by the gap between the stencil and substrate. The influence of many parameters on the geometrical and diffusion contribution to blurring has been investigated. It has been shown that blurring is material dependent, and increases with deposition rate, amount of deposition material, substrate temperature and deformation of the stencil. To compensate for blurring effects, a post-processing corrective etch can be performed. Another method is to use micro hotplates embedded in the stencil to bend the stencil and correct the blurring.

Year of review paper: are there any newer review paper published

This paper is from 2014, a couple of review papers were published later (one in 2017 by American authors and one in 2018 by Korean authors). No more recent review papers specifically focused on stencil lithography were found)

Quality of review paper; did authors make original content e.g. figures/tables to compile data from literature?

The authors did not make original content, but some of the work that is cited is theirs.

Anything else relevant

Stencil lithography has been used in many different applications, for example in plasmonics and gratings for solar cells, electrical contacts in 2D materials, transistor fabrication on non-planar substrates, magnetic nanostructures, plasmonic biosensing, cell and protein patterning, flexible devices, fabrication of nano-imprint lithography stamps, mechanical mass sensors integrated with CMOS and atomically defined contacts and devices.