Position Paper: Maskless Submicron Fabrication Techniques: Any Future?

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Abstract: Diffraction-limited laser (photon) beams provide the basis for a plethora of micromachining processes, with spatial resolutions of the order of the wavelength of the laser source. Advantages of laser-beam over focused-ion-beam tools in terms of operation in free atmosphere, higher removal rates and compactness are well known. Near-field laser fabrication techniques capable of breaking the diffraction barrier thus allowing micromachining of features an order of magnitude less than the wavelength of the source have been known well before Bbetsig, et al. [1] have re-invented them. Laser-assisted chemical deposition techniques complement the well-explored subtractive (machining) laser processes with an additive process. It is the position of this article that the exploration, invention, adaptation and perfection of laser-based microfabrication processes will continue to grow down to the submicron scales with significant impact in the rapid prototyping (RP) of MEMS.

Mask-based fabrication processes: micro-fabrication concepts, tooling and devices covering scales ten orders of magnitude less than a centimeter, i.e. Down to an order of magnitude just above the atomic size, is now a proven capability that aspires to grow into a main infrastructure technology for the 21st century [2]. Traditionally, the semiconductor industry has been the main driver of miniaturization as reflected by a continuous and consistent improvement in the transistor performance according to Moore's law. However, downscaling limitations have already been identified both in terms of fundamental limits in physics and in manufacturing. As an example, even the cornerstone semiconductor fabrication process of conventional (refractive) optical lithography, which sustains the 0.18 and 0.13μm technologies, is anticipated to reach a limit at the 157nm light source wavelength beyond which significant issues arise in terms of availability of light sources and the need for new photoresist materials [2]. And yet, the semiconductor industry is optimistic, as reflected by the Semiconductor Industry Association's (SIA's) ITRS (International Technology Roadmap For Semiconductors) roadmap for the projected minimum feature size in lithography (Fig. 1).

A number of candidates for next generation lithographies (NGL) have been proposed [2]. They include:

- EUV (Extreme UV Lithography)
- EPL (Electron-projection lithography) and EBDW (electron-beam direct-write)
- PXL (proximity X-ray lithography)

Variants of the semiconductor fabrication processes are already in use by foundries that provide MEMS fabrication services where the customer "rents" real estate on a wafer. A number of designs are batch-processed in one run, which is usually rated at a cost of $3000 for one square inch wafer space with a lead-time of about one month.

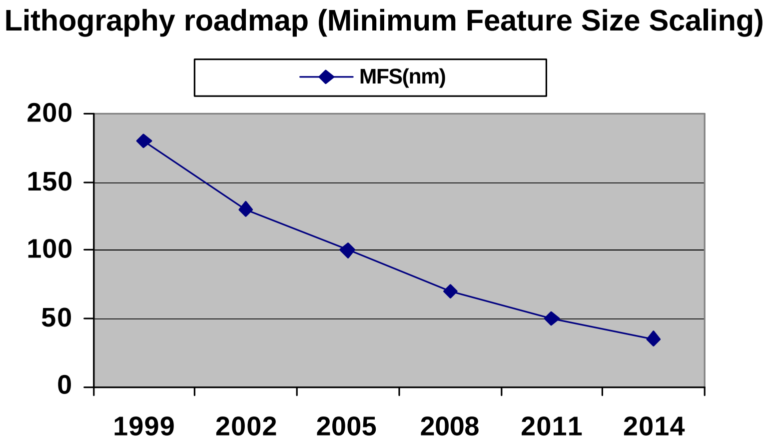

Fig. 1: Scaling projections of the minimum feature size (MFS) of conventional refractive optical lithography (ROL) for the upcoming decade. Source: ITRS Roadmap, 1999.

Mask-less Fabrication Processes: Irrespective of the NGL direction the Semiconductor Industry will choose, it is instructive and noteworthy that despite the serial nature of direct-write processes, EBDW is still listed as one of the NGL solutions. The current article claims that there is a need for low-cost, low lead-time, mask-less, direct-write R.P. processes for MEMS. Possible candidates for such processes are:

- Confocal and/or Interferometric and/or Near-field laser techniques
- Laser microchemical deposition techniques
- Focused ion beam (FIB), alias: ion beam direct write (IBDW)
- Focused electron beam (FEB) alias: electron-beam direct-write (EBDW)

Such processes are already in use in the semiconductor industry for physical silicon debug and circuit editing (repair and restructuring) as well as deposition of metal interconnects for probing, testing and restructuring of flip-chip package interconnects [4]. Transfer of such principles in the MEMS fabrication arena should be possible and is explored at ASU as part of our on-going research [5] along with time-sharing and energy-sharing techniques for improving the fabrication time of serial tools.

Fabrication Capabilities = Subtractive + Additive + Re-Shaping Capabilities: The inclusion of laser sputtering and laser microchemical deposition in the gamut of laser microfabrication processes has rendered the laser as an indispensable generic component of future micro-scale and possibly sub-micron fabrication tooling. Given our experience with the diversity and non-standardization in MEMS fabrication processes this far, the R.P. tooling for MEMS is expected to be a "mosaic" where "mix-and-match" solutions will be defining the overall MEMS fabrication process rather than a single, one-stop, turnkey process.

CAE/CAD/CAM Process Development: The CAD/CAM tools available for 2-D and 3-D patterning of standard laser and FIB tools are studied and evaluated in an effort to provide common interfaces with standard MEMS CAD tools (e.g. AutoMEMS, MEMCAD) or well as standard R.P. CAD tools (e.g. ".STL" File Slicing Algorithms). Such a development will certainly expand the capabilities of laser and FIB/FEB tools and render them "good partners" in the R.P. for MEMS. The integration of CAE tools (e.g. for process specification and automated decision making) with CAD/CAM is yet another significant enabler for R.P. for MEMS.

Mix-and-Match Processes: Thin and thick film Laser vs FIB Assessment: Thin and thick film deposition techniques are routinely used at ASU to deposit a diversity of materials on substrates (e.g. Si or SOI wafers) [7, 8]. Laser processing of magnetic films (NiFe and Co/Pt) on Si substrate is investigated for the R.P. of magnetic microfluidic devices [9] and mix-and-match FIB processing of Invar and Au, Cr and Ti layers for stress-relief and next generation optical materials (e.g. CaF2) open up new directions for future research.

Conclusions:

1. Rapid prototyping (RP) tools for MEMS will aid the further evolution of the field. Traditional and novel laser techniques, along with FIB/EB patterning and metrology tools, are expected to provide "mix-and-match" MEMS microfabrication solutions much needed for experimentation, prototyping and testing of low-volume MEMS products.
2. Integrated CAE/CAD/CAM tools for MEMS process flow, control, calibration and automation tools are essential in improving MEMS prototyping and testing.
3. Construction of roadmaps for the multitude of functionalities offered by MEMS, comparable to SIA's ITRS roadmaps with an outlook of 10-15 years ahead, should in principle be possible and will indeed constitute a great advancement in the research in the manufacturing sciences for MEMS.

References:

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