# SUEX Dry Film Resist – A new Material for High Aspect Ratio Lithography

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## Abstract

SUEX epoxy Thick Dry Film Sheets (TDFS) are a promising material for a wide range of MEMS applications. They contain a cationically cured modified epoxy formulation utilizing an antimony-free photo acid generator (PAG). A highly controlled solvent-less process provides uniform resist coatings between two throw-away layers of protective polyester (PET) film in varying thicknesses ranging from 100 µm to 1 mm. Patterning is possible with both UV and X-ray lithography as well as a combination of lithography and hot embossing. This enables the fabrication of multi-level, complex designs as well as high aspect ratio MEMS (HARMS) components. Joint efforts between DJ DevCorp and CAMD are focused on optimizing process parameters and demonstrate the possibilities for MEMS applications including plating molds for metal microparts, polymer MEMS, multilayer microfluidics structures, BioMEMS, medical devices, wafer level packaging processes, and displays. This report briefly summarizes the activities and refers to the literature or other contributions in the CAMD annual report for more details.

## Introduction

DJ DevCorp is developing thick epoxy dry film resist technology based on licensed epoxy resists and thick dry film technology. Work on these materials was initiated at MicroChem in 2006 mainly addressing needs from the HARMS community and preliminary thick dry film sheets up to 1mm thickness were successfully prepared and patterned at the CAMD bending magnet X-ray beamlines and presented at HARMST 2007 [1]. Work presented at HARMST conferences 2001 to 2009 show the strong interest of the LIGA community to replace the commonly used yet insensitive and therefore expensive PMMA X-ray resist and the struggle associated with liquid epoxy resist formulations and achieving repeatable, reliable results esp. in thick resists. Based on our initial, promising results discussed at HARMST 2007 in Besancon further material engineering was undertaken to address issues of manufacturability, stability, resist processing, and overall structure fidelity. Recently, results on the next generation material have been published [2,3,4] using SUEX sheets in UV lithography where it shows great market potential including plating molds for metal microparts [5,6], polymer MEMS, microfluidics, BioMEMS, medical devices, wafer level packaging, optical spacers, and embedded devices.

As part of our recent studies, resist layers ranging from 100 to 1000µm in thickness were processed with UV and X-ray lithography on different substrates (silicon wafers with and without seed layers, SUEX substrates (structured and non-structured), PET, PMMA, and other polymer materials) with a variety of structures demonstrating the potential for MEMS applications.

## Experimental

Resist application on either substrate is simple. In preparation the substrate is thoroughly cleaned and placed face up onto a 1mm thick aluminum sheet. A simple office laminator, for example GBC Heat Seal H600 Pro or Think&Tinker Model 4250 is used for our current process. First place the substrate face up on an aluminum carrier. A ruler placed at the backend of the stack or a PET sheet between the two prevents full contact between substrate and resist and ensures best lamination results. For lamination the stack is moved through the heated rollers at a speed of 1ft/min at 65-75°C depending on the thickness and thermal conductivity of the carrier, the resist, and the substrate. The ruler or PET sheet is withdrawn just before reaching the rollers. A lower roller temperature is used when applying a cover sheet onto a structured substrate.

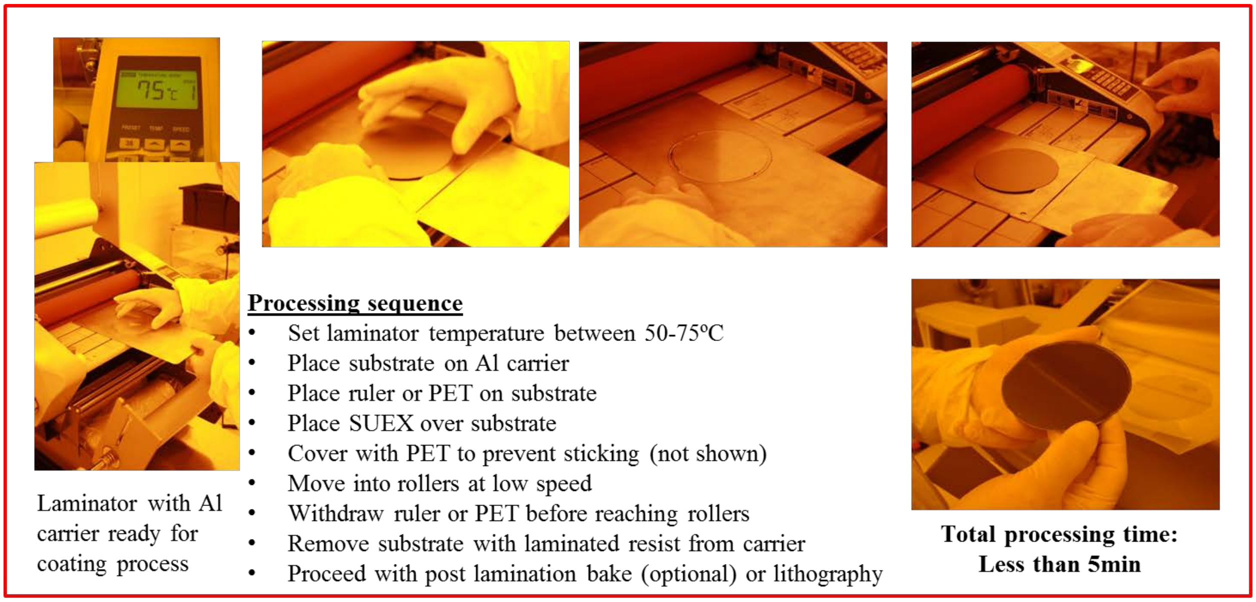



Figure 1: Substrate preparation of SUEX resist on a silicon wafer.

While this simple process works well for thinner films less than 250µm in thickness, thicker laminations need to be placed within a template or guide. The shim should be slightly thicker (50-150µm) than the combined thickness of the wafer, the SUEX film and the PET coversheet and should be slightly larger than the wafer size and shape and attached by tape or adhesive to the Al carrier. This is to allow the roller gap to more gradually open up to the stack thickness to be laminated and prevent the parts from moving during the lamination process.

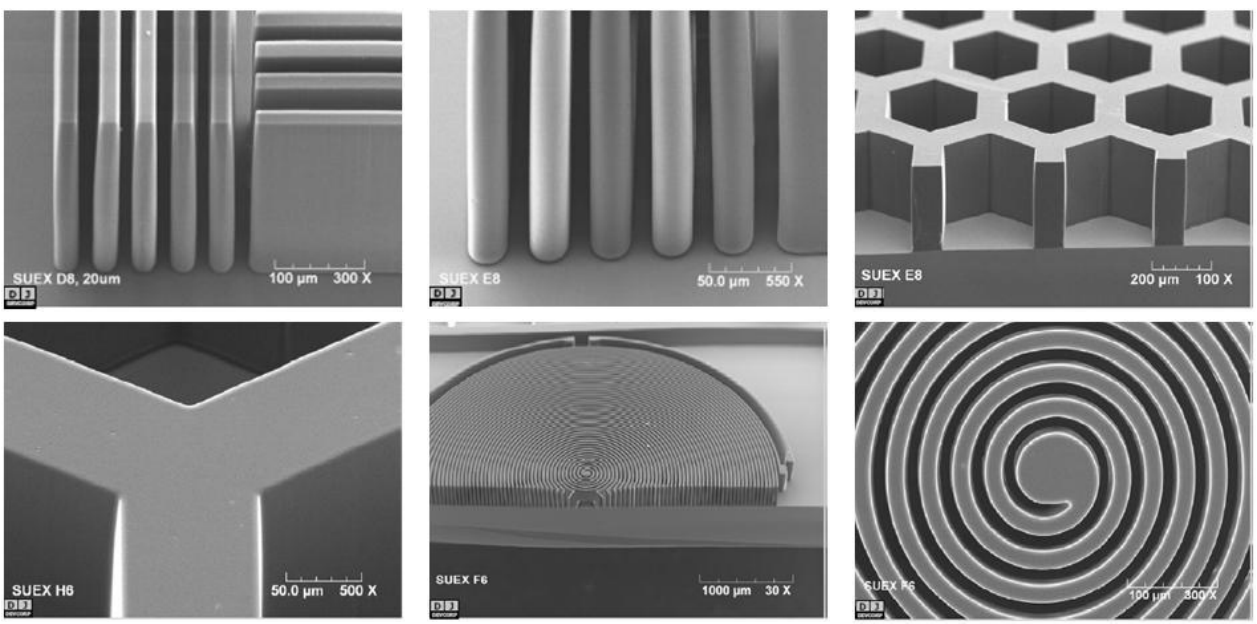
An optional post lamination bake (PLB) can be used to remove various coating defects from the laminated films and completes the substrate preparation process. Bake of the laminated substrate with the PET coversheet still in place on a leveled hot plate or oven with the laminate facing up, at 65-70ºC for 10-15 min or at 85-95ºC for 2-5 min will give very smooth surfaces for best substrate/ resist contact during lithography. The laminated substrate can now be stored until needed.

The imaged and cured laminated sheets give very high resolution and aspect ratios with high performance vertical sidewalls and excellent thermal resistance. For our UV experiments 100 to 250µm thick sheets of SUEX TDFS were laminated to 100mm (4") silicon wafers, the protective coversheet removed, and imaged with a typical exposure dose from 600 (100µm) to 1000-1500 $mJ/cm^2$ for 250µm thick sheets on a contact aligner (SUSS MA6, Quintel UL 7000) with a 350nm cut-off light filter. When working with other substrates, significant changes in dose may be required. For exposures on Au or Cu, we recommend increasing the dose 1.5 to 2 times. The use of a light filter to remove wavelengths below 350nm during exposure is required if high resolution, high aspect ratios and straight sidewalls are desired. Broadband, unfiltered exposures can be used where geometries are large and wall profiles are not critical. X-ray exposures into resist heights up to 2 mm have been done with a bottom dose ranging from minimum 90 up to 300 $J/cm^3$. Typically 180 $J/cm^3$ are structures with aspect ratios up to 40. Top-to-bottom dose ratio is set to below 4 using filters. The PEB parameters determine optimum resolution and line edge quality. For the TDFS structures a two-step process is recommend. A first step at 55 - 65ºC for up to 30min is followed by an 85-95ºC bake for up to 4 hours. Ramping the PEB bake from 65ºC to 95ºC over about 10min using a rate of 3ºC/min will improve resolution. A slow ramp-down to RT temperature (typically 5-8ºC/hr) completes the process. It should be noted that resist thickness and substrate material determine the best choice of parameters and will require some fine-tuning for each MEMS design.

Developing is done at room temperature or warmed up to 30ºC with the wafers face-down in PGMEA developer and gentle agitation. Typically large areas of 500µm thick SUEX are developed in about 30min while finer structures may require a total time of up to 4 hours for this height. A 2-step procedure splitting half the time in a first bath removing most of the unexposed resist followed by immersing it in a fresh PGMEA bath for residue-free cleaning has been proven beneficial for HARMS pattern. Development is completed with a thorough IPA rinse for up to 1hr removing excess developer and vacuum drying. After development a final bake at 85-95°C or an optional hardbake at higher temperatures up to 160°C for 1hr (plus 2hrs of ramp down time) completes the fabrication.

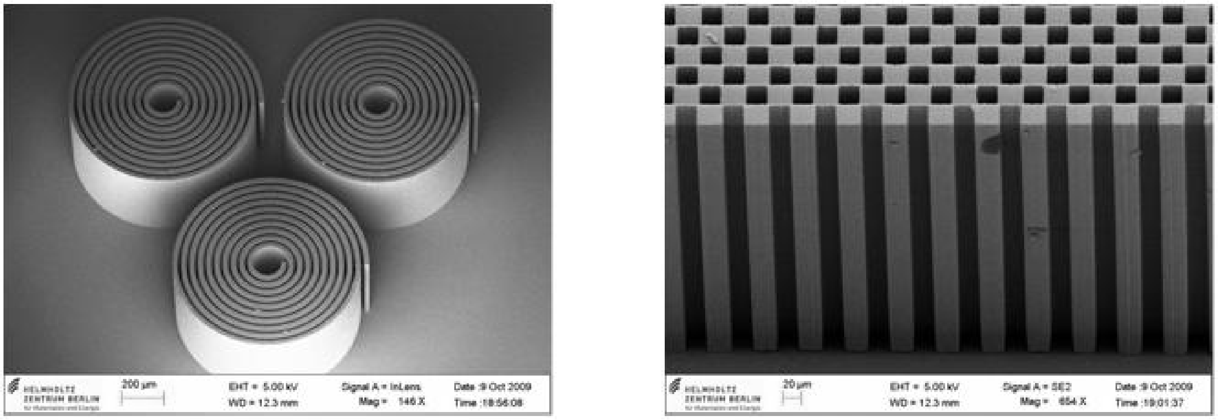
## Results

With our initial films and process conditions we have been able to obtain greater than 15:1 aspect ratios in 250µm thick sheets using contact exposures on an optical aligner, Figures 2.




Figures 2: Examples of structures patterned in 250µm thick SUEX sheets by menas of UV lithography: lines and spaces demonstrating 20µm resolution (top left, center); MEMS cell/cavity structure with 100µm wall width (top right and bottom left); spring feature with 20µm coil width (bottom center and right). Support from G. Ahrens, mrt GmbH, Berlin, for these experiments is gratefully appreciated.

The majority of our experiments have been done with X-ray lithography [7,8,9] (also see CAMD Annual Report by S. Lemke entitled: *Negative Resists for Ultra-Tall, High Aspect Ratio Microstructures*). Some examples of structures presented in Figs 3a-c with heights ranging from 100-1000µm illustrate the possibilities of this new material and suggest potential use in MEMS [10].



Figs. 3a: 20µm SUEX structures in 500µm height patterned at BESSY II, Helmholtz-Zentrum Berlin (HZB) using a bottom dose of 140 J/cm$^3$; Support from S. Lemke and T. Selinger, HZB/BESSY, Berlin, for these experiments is gratefully appreciated.

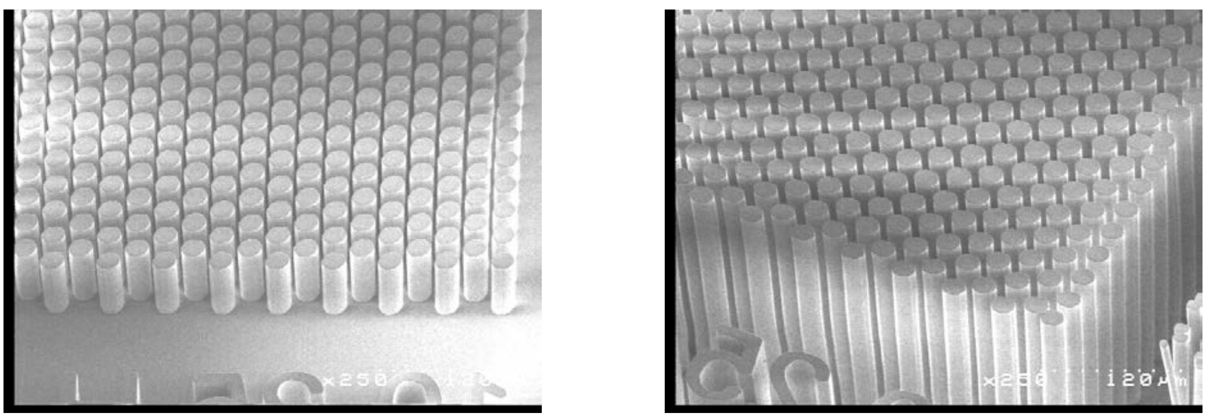


Fig. 3b: 25µm densely packed posts with a height of 100µm (left) and 350µm (right) patterned at CAMD.

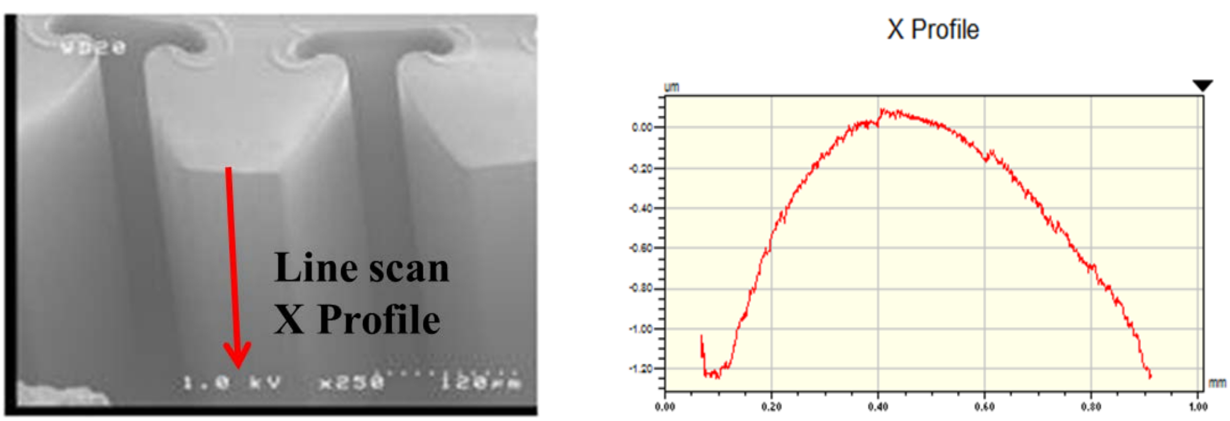
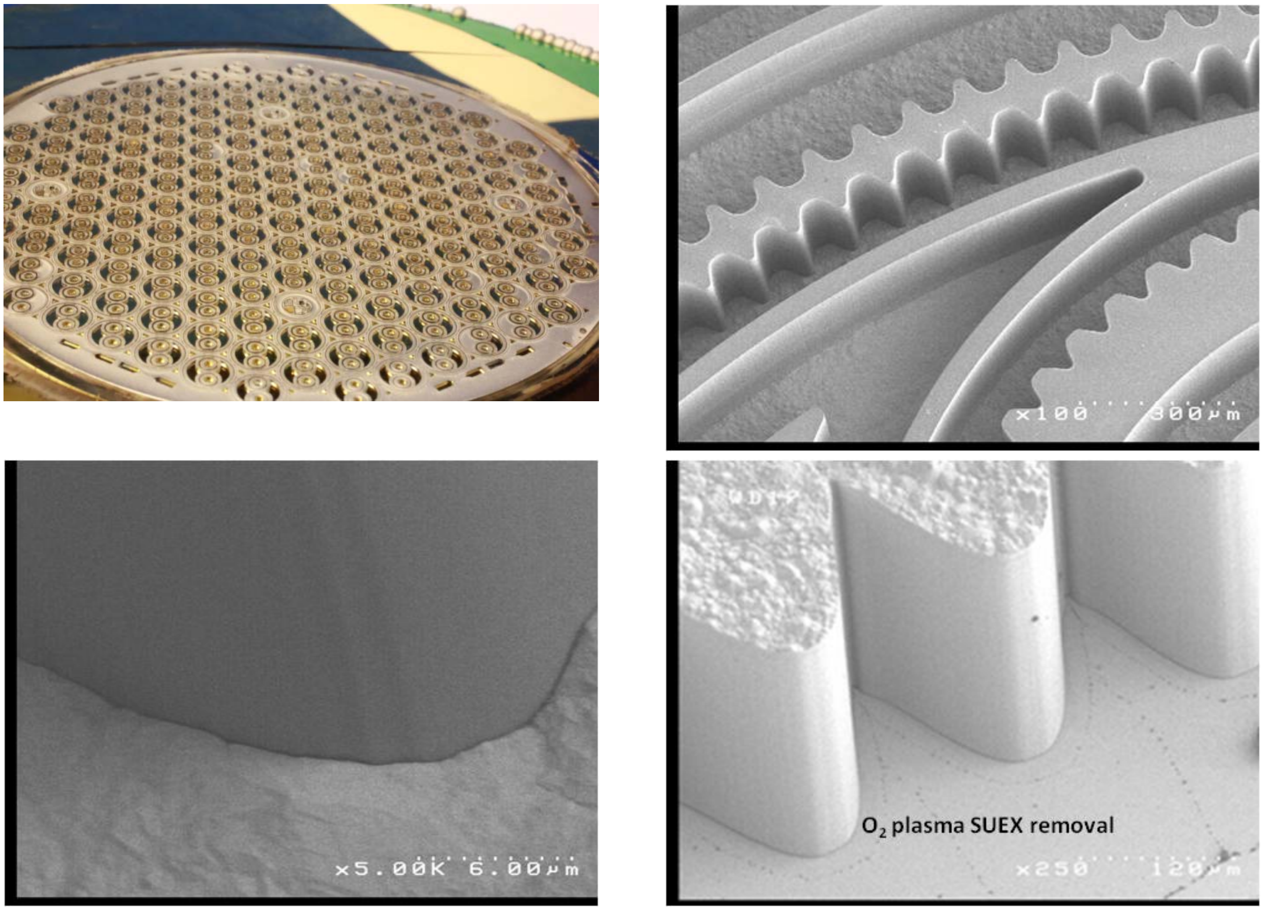



Fig. 3c: Approx. 1mm tall sidewall of a gear structure (left) and measured sidewall profile using a WYKO NT3300 white light interferometer (right) showing a slight bow and an average deviation from a vertical sidewall of about 0.1µm/100µm height.

Using SUEX structures as templates for electroplated metal parts is illustrated in Figs. 4. The SUEX pattern was laminated onto a Si substrate with Ti/Au seed layer and patterned with optimized process parameters (bottom dose of 120J/cm$^3$, PEB at 75ºC for 12 hours) to ensure minimum internal stress and maximum adhesion of the structures.




Figs. 4: Plated gear mold, ~300µm thick Ni in 600µm SUEX; top left and right - overview and detail after plating process; bottom left - close up of SUEX/plated Ni interface; bottom right – Ni structure after $O_2$ plasma removal of SUEX (thank you to S. Lemke, HZB/BESSY, Berlin, for removing the SUEX resist using the R3T asher).

A major advantage of SUEX dry film resist is the ease of making multi-level HARM structures as indicated in the process schematic shown in Fig. 5. This process will create multi-level SUEX structures on a SUEX substrate combining optical and X-ray lithography steps. Note that in Step 7 SUEX resist is embossed into a substrate with patterned HARM structures using a vacuum molding machine (HEX 2, Jenoptik, Jena, Germany) without any structure damage. Figures 6 show some of the structures made by this process. The total height was ~1.1mm with steps of ~250 and 750µm, respectively. The first level (not shown) was patterned by UV lithography while levels 2 and 3 were exposed with x-rays. It also worthwhile mentioning that this approach is dramatically simpler and faster as previous efforts reported in [11,12].

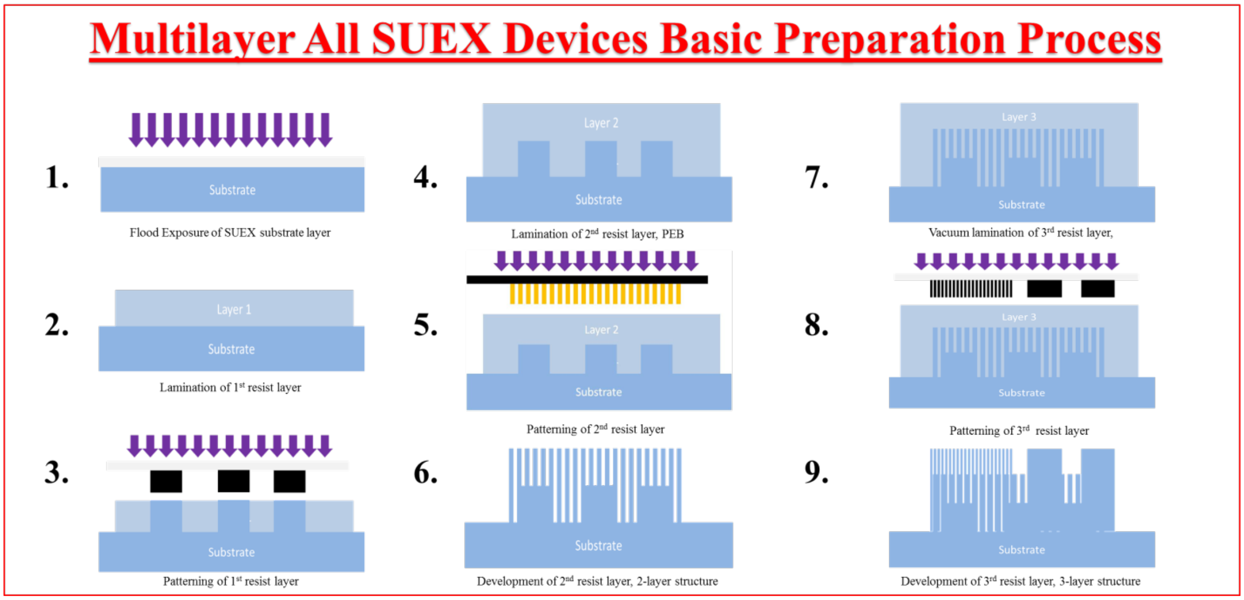
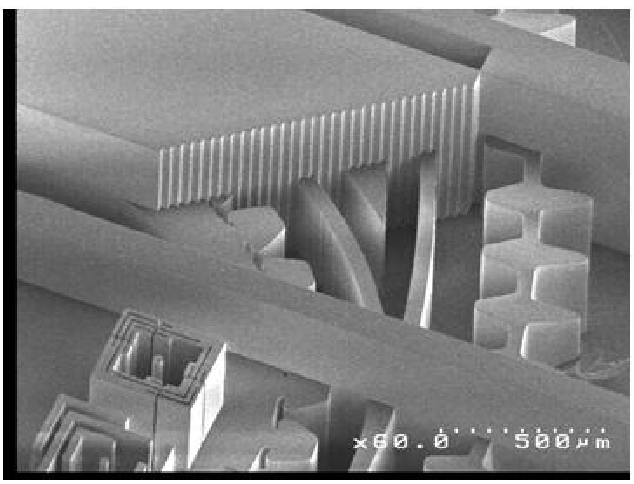
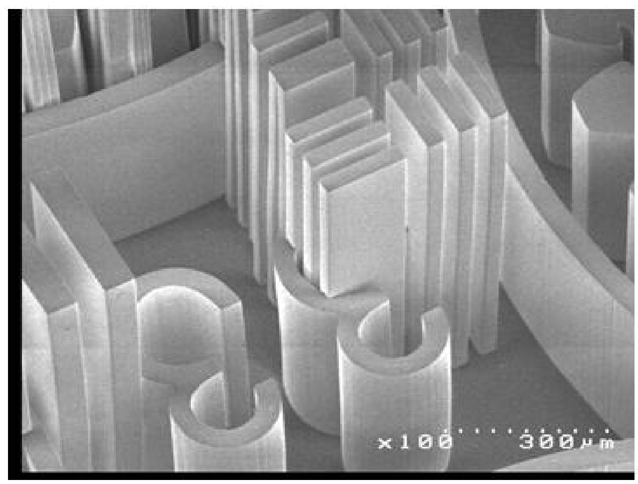



Fig. 5: Process flow fabricating a 3-level all-polymer microfluidic chip with two patterned layers.



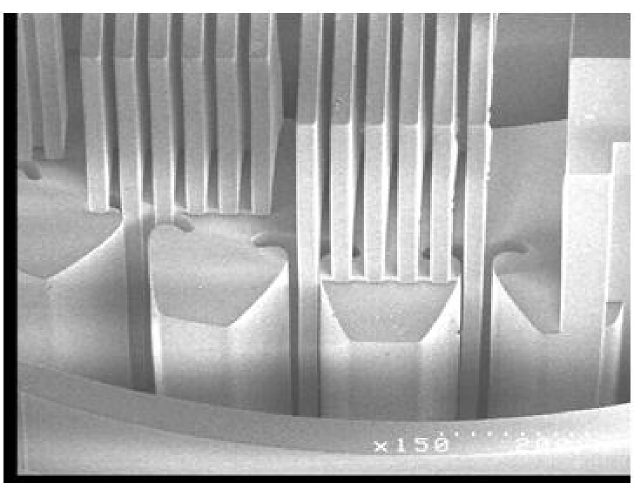




Figure 6.

Example of 3- level test structures with heights varying from 250-1100µm; smallest structures are 10µm (grating features on 1100µm tall wall).

The 2nd layer was fully developed and refilled with resist forming the 3rd layer. Picture to the left shows that even fine structures (gears) were completely filled in this process and could be nicely patterned.

## Summary

In conclusion SUEX TDFS provide a new generation of negative resist materials that can be used with UV and X-ray lithography offering improved LIGA based HAR MEMS microstructure fabrication with regard to reliability, throughput, and manufacturing costs. For many years the PMMA based LIGA process has always been considered *temporary* because of its lack of sensitivity resulting in long exposure times and high fabrication costs. SUEX has the potential to be a replacement from its processing ability (like PMMA it's a sheet material and relatively easy to process), its speed, and its performance. SUEX TDFS have been successfully used to make a number of MEMS structures including templates for electroplated metal parts. A major advantage is the easy fabrication of multi-layer MEMS components and devices.

Our current results using SUEX TDFS as a resist in X-ray lithography show great promise in preparing HARMST structures with very high aspect ratios and image fidelity. The benefit of using dry laminate resist is a simple, highly reliable resist application process that is suitable for mass production and is flexible enough to be adapted to different substrate materials and dimensions.

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