Release of MEMS devices with hard-baked polyimide sacrificial layer

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ABSTRACT

Removal of polyimides used as sacrificial layer in fabricating MEMS devices can be challenging after hard-baking, which may easily result by the end of multiple-step processing. We consider the specific commercial co-developable polyimide ProLift 100 (Brewer Science). Excessive heat hardens this material, so that during wet release in TMAH based solvents, intact sheets break free from the substrate, move around in the solution, and break delicate structures. On the other hand, dry reactive-ion etching of hard-baked ProLift is so slow, that MEMS structures are damaged from undesirably-prolonged physical bombardment by plasma ions. We found that blanket exposure to ultraviolet light allows rapid dry etch of the ProLift surrounding the desired structures without damaging them. Subsequent removal of ProLift from under the devices can then be safely performed using wet or dry etch. We demonstrate the approach on PECVD-grown silicon-oxide cantilevers of 100 micron × 100 micron area supported 2 microns above the substrate by ~100-micron-long 8-micron-wide oxide arms.

Key words: ProLift, hard-baked, sacrificial layer, MEMS, cantilever, etch, RIE, release

1. INTRODUCTION

Microelectromechanical systems (MEMS) frequently employ moveable structures built upon a sacrificial layer, which is dissolved or etched away at the end of the fabrication process to release the structures. Examples include suspended cantilevers anchored at one end or bridges fixed at both ends. Removal of the sacrificial layer may be achieved either by wet or dry etching [1]. Different sacrificial materials are commonly used, such as silicon-based materials, polyimide, etc. [2-3]. Achieving functional free standing structures is sometimes complicated by hardening of sacrificial material after multi-step processing [4-5]. This paper presents our solution to release of a free-standing MEMS cantilever from hard-baked commercial co-developable polyimide (ProLift 100, Brewer Science) sacrificial layer.

2. FABRICATION PROCESS

ProLift 100 (Brewer Science) is a polyimide that is soluble in positive resist developers. However, we experimentally found that it can be paired with both positive and negative resists which have TMAH base, such as MF319, RD6, etc. It features good resistance to acids and organic solvents. Although ProLift 100 is specified to withstand temperatures exceeding 300 C, we found that removal becomes more and more difficult the longer it is baked, even at temperatures within this limit. Such long baking is unavoidable in multi-step processes, including for example steps that involve PECVD growth of oxide.

Four-types of ProLift 100 provide different spin-on thickness ranges. All experiments in this work have been done on ProLift 100-20 which gives thicknesses in the range ~1 to 4 micron.

Our MEMS device requires eight mask steps using both positive and negative photoresist. The most heating caused by PECVD of silicon-oxide on top of the ProLift, 2 microns above the substrate, which bakes the ProLift at 300 C for ~30 min. This oxide comprises the main structural material of the cantilever.

3. PROBLEM

Control of wet co-development is critical since ProLift dissolves in the resist developers faster than photoresist itself. Co-development time depends on the type of photoresist used and on pattern dimensions. Figure 1 presents our data for development vs. time in MF319 (2% TMAH) at room temperature using PMMA as wet etch mask for 100 micron pattern size in as-spun 1.5 micron thick ProLift without the usual hard-baking that results during our process (Solid triangles). This result shows that the ProLift is completely developed down to the substrate in about 50 seconds. Smaller patterns develop more slowly. Open triangles represent data for the same process on hard-baked ProLift, where it is obvious that the development rate has been reduced by more than a factor of 2.

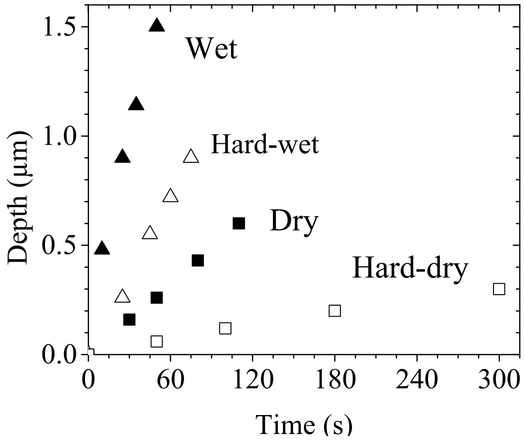

Figure 1. (Solid triangles) Wet development depth vs. time for bare 1.5 µm thick Prolift100-20 in MF319 developer at room temperature with PMMA mask and 100 micron pattern size. (Open triangles) Wet development for hard-baked ProLift (30 min at 400 C) with other conditions the same. (Solid squares) Dry plasma etch depth vs. time for 1.2 µm ProLift and 1 mm pattern size (Open squares) Dry etch data for hard-baked ProLift with other conditions the same.

Dry etch depth vs. time is plotted in Fig. 1 for 1.2 micron thick ProLift100-20 without long time hard baked, and 1.5 micron thick ProLift 100-20, which has been hard baked at 300 C for 30 minutes. Etching was done using Trion RIE with 100 W RF power, 750 mTorr pressure, 98 sccm O$_2$, and 2 sccm CF$_4$ flow rate [6]. Brewer Science has reported different dry etch rates using different equipment and recipe [7].

After spinning ProLift, our process involves 11 minutes of photoresist baking at temperatures in the range 110 - 150C and ~30 min at 300 C in the PECVD chamber during oxide growth. This excessive heat hardens ProLift so that release by either wet or dry method more difficult and takes longer, as shown in Fig. 1. Development of 2 micron thick un-baked ProLift takes a little over 1 minute in MF319 (2% TMAH), but after baking complete removal from under the cantilever paddle takes hours. We experimented with different solvents, including MF319 (containing 2% TMAH), 5% TMAH solvent, and ProLift remover (Brewer Science). In all cases, the hard-baked ProLift came off in slabs like “ice-floes”. These move around on the surface, even without intentional agitation, and collide with the cantilevers, shearing them off. Optical microscope images of free floating ProLift slabs and a damaged cantilever are presented in Figure 2. The floating sheets of ProLift are evident above and below the arms in the left image and on top of the contact pad on the right side of the right image.

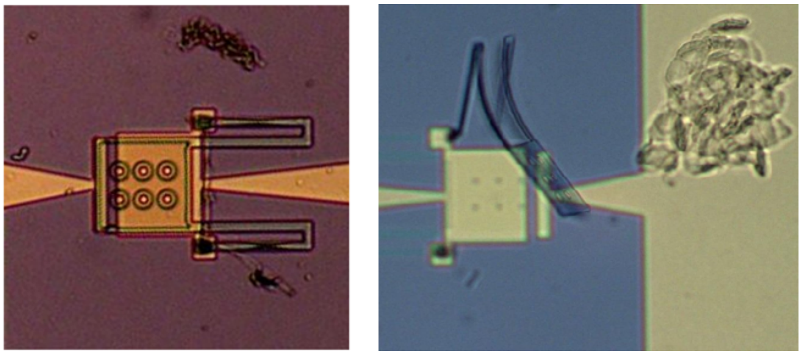

Figure 2. (Left) Optical microscope images of cantilevers during wet release process in MF319. ProLift sheets are coming off the structure. (Right) A cantilever broken by floating intact sheets of ProLift.

In the case of dry etch in oxygen plasma, long times are required to release cantilevers from hard-baked ProLift. During this process, physical bombardment by the plasma ions damages the cantilevers, as shown in Figure 3. Here the cantilever arms appear badly eroded while the paddle is still incompletely released. Additionally, black residue is left on the surface.

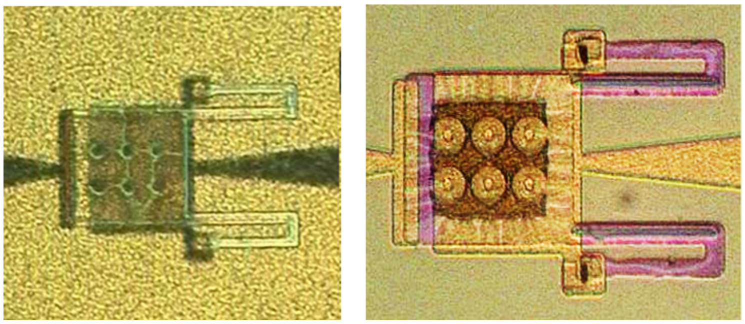

Figure 3. (Left) Black residue left by dry etching hard baked ProLift in oxygen plasma. (Right) A cantilever that has been partially released from hard-baked ProLift sacrificial layer by 55 minutes of oxygen plasma etch. The cantilever arms appear badly eroded by ion bombardment.

4. SOLUTION

Our solution is a multi-step release process. First, we blanket expose the entire wafer with UV light at the range of 300-400 nm wavelength for six minutes using the source from our mask aligner. ProLift strongly absorbs this wavelength, according the spectrum in Fig. 4. This spectrum was measured in reflectivity R using a Perkin-Elmer UV-Vis spectrometer. The ProLift was deposited on a metal-coated substrate, so that there was no transmittance, and absorptance is given by 1-R.

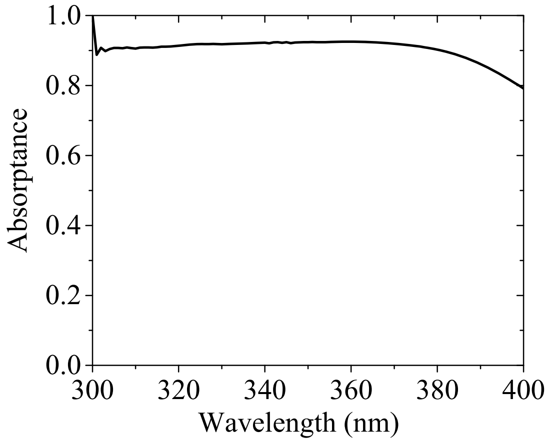

Figure 4. Absorption spectrum of ProLift in the range of 300-400 nm wavelengths.

Our hypothesis was that UV exposure would break the chemical bonds formed during heat treatment and at least partially reverse the hardening and resistance to etching. We did indeed find that the ProLift surrounding the cantilevers was released in MF319 developer after the UV exposure ~10-20% faster compared with wet release without exposure. With most of the surrounding ProLift gone, the potential for large slabs to break free and bulldoze the cantilevers was essentially eliminated. Still, to protect the delicate arms and anchors, these were covered by a PR mask, while the sample was soaked in MF319 developer for a time sufficient to remove the ProLift from under the paddles. Then we stripped the PR and placed our sample into a dish of fresh solvent to release the arms. Optical microscope images of the intermediate steps of releasing the paddle, and finally the arms are presented in Fig. 5.

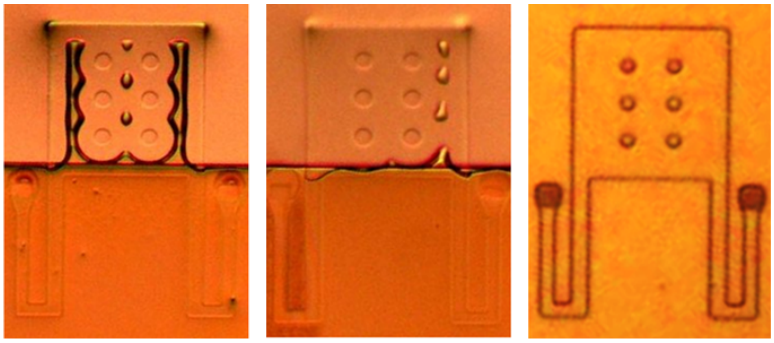

Figure 5. (Left) A partially released paddle after 12 minutes in MF319 developer, while arms and anchors are covered by PR. (Middle) Paddle is almost released after 22 minutes in MF319 with PR still present. (Right) PR is striped and the whole cantilever is soaked in fresh MF319 developer, fully releasing the cantilever after 13 minutes.

Instead of using wet developer to remove the ProLift under the paddle, dry oxygen plasma etch could also be used. Prolonged dry etch can cause physical damage to the cantilever (Fig. 3), but the UV exposure sped the process and spared the oxide cantilever from significant damage. Dry etching gave us cantilever yield exceeding 90%, and the surrounding substrate became more smooth and clean than with wet release. Fig. 6 presents the intermediate steps in the dry release. Etching was done using Trion RIE with 100 W power, 900 mTorr pressure, 98 sccm O_2, and 2 sccm CF_4 flow rate. Figure 7 presents SEM images of fully released device.

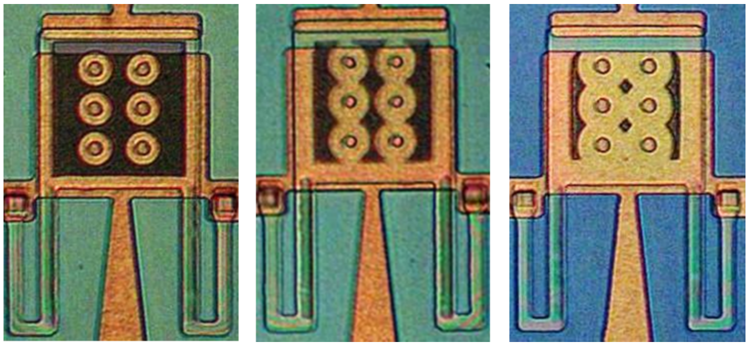

Figure 6. (Left to right) Optical microscope images of the stages of cantilever release after 60, 90, and 120 minutes O_2 plasma etch.

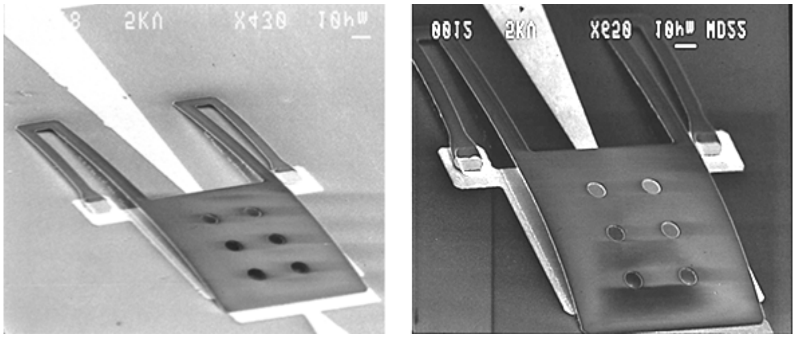

Figure 7. (Left) SEM image of completely released structure with 430X magnification, 38 working distance (WD), and 5 kV high voltage. (Right) SEM image of another released structure with 650X magnification, 22 WD, and 5 kV.

SUMMARY

Removal of polyimides that are used as sacrificial layer in fabricating MEMS devices can be challenging after hard-baking, which may easily result by the end of multiple-step processing. UV exposure allowed rapid dry etch of the ProLift surrounding the oxide cantilevers, which eliminated the risk of large floating sheets sheering the cantilevers from their anchors. Then the remaining ProLift under the cantilevers could be removed by either wet developer or by additional oxygen plasma etch.

ACKNOWLEDGMENT

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