A FACILE DRY-PMMA TRANSFER PROCESS FOR ELECTRON-BEAM LITHOGRAPHY ON NON-FLAT SUBSTRATES

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ABSTRACT

This paper presents a simple yet powerful technique that enables the use of high resolution e-beam lithography on irregular substrates by transferring a Dry-Poly (methyl methacrylate) (PMMA) film. The Dry-PMMA film can be patterned and developed via electron-beam lithography before or after the transfer depending on the applications. Then the film can easily be transferred to non-flat or fragile substrates including the sharp tip of a sewing needle, a conical surface, the edge of a silicon wafer, and suspended structures. Specifically, this paper focuses on a transfer method of pre-pattered Dry-PMMA film on sharp substrates. This technique can be applied to a broad range of applications in micro- and nano-technology research areas where a conventional photo-resist spinning method is not available.

INTRODUCTION

E-beam lithography, a powerful method to create micro and nanoscale patterns, has been widely used in engineering and other science fields [1]. As electron beam lithography requires uniform coverage of electron beam resist on the substrate, a flat-surface that is adequate for spin-coating is desired. Because irregular substrates do not share this characteristic, performing e-beam lithography (EBL) on them can be a challenging task [2][3]. Various approaches to perform EBL on an irregular surface have been made such as spray coating [4], photoresist (PR) evaporation [5], and dry-film PR [6]. However, most of those methods involve complex processes, special equipment, lower exposure sensitivity, or expensive materials [7]. Specifically, the spray coating method, adequate for plane and sharp edges of trenches, requires special tools such as an ultrasonic spry nozzle and a customized mixture of PMMA, Methyl-ethyl ketone (MEK) and Propylene glycol methyl ether acetate (PGMEA), to realize the PMMA coverage on a non-flat surface. In the PR evaporation method, a polystyrene, as a photo resist, is thermally evaporated on irregular or fragile substrates. However, achieving uniform coating is challenging as it requires special processes such as the rotating and tilting of a substrate during evaporation. Moreover, the method reduces molecular weight for evaporation as a result of thermal decomposition. Thus, coated PR film has lower exposure sensitivity than general source materials. Lastly, use of a dry film resist (Shipley 5038) is reported in which special tools for laminating and collimating UV system is required for the exposure of the film [6]. In general, a process using the dry film resist is associated with complicated steps and a high cost process that contribute to limits the wide adoption of the process to other applications.

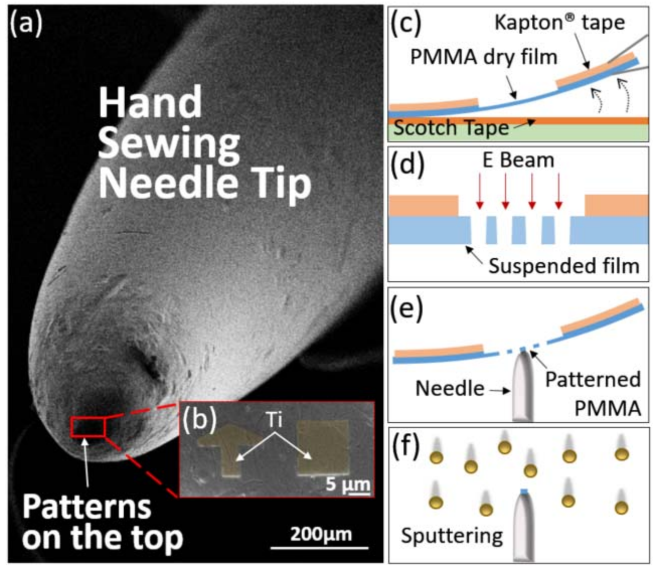


Figure 1: Schematic view of pre-E beam process. (a) SEM image of the hand sewing needle tip with arrow and square pattern on top of it (b) created via pre-E beam transferring process followed by lift-off (b~f). Details of each steps of fabrication process will be explained in Fig. 3 (a~c).

This paper presents a new process in which pre-spun PMMA film is transferred to the challenge target substrates. Chang et al. previously unveiled dry-film transfer using open cavity, where the transfer of post-pattered PMMA film is demonstrated [8]. This paper advances the idea by employing pre-pattering of PMMA and transfer of the film to the sharp tip which was not possible with previous approaches. As shown in figure 1, various patterns can be created on irregular substrates including sharp sewing needle tip with a simple process flow. Fig. 1(b) shows an SEM image of the arrow and square Titanium lift-off on the top of the sewing needle. Right panels on Figure 1 briefly describe the fabrication process. The pre-spun PMMA is possible to be peeled off as a dry condition between a Kapton tape and a Scotch tape in Fig. 1(c). Then, the suspended dry-PMMA film can contain micro scale patterns via EBL (Fig. 1(d) and Fig 2). Lastly, a Ti sputtering and lift-off is followed by ultrasound cleaning to remains metal patterns on the irregular shaped target in Fig. 1(f)[9]. The new fabrication techniques in this paper have distinct advantages over previous methods. First, the key role technique, the dry PMMA film transferring, is accomplished under normal pressure and under room temperature [10]. Second, the technique does not demand high-cost equipment for transfer. Liquid PMMA film is deposited using spin-coater followed by a short bake process on a hot plate. In terms of materials, the process utilizes the PMMA A4, Scotch tape, and Kapton tape that are available in most research laboratories [11].

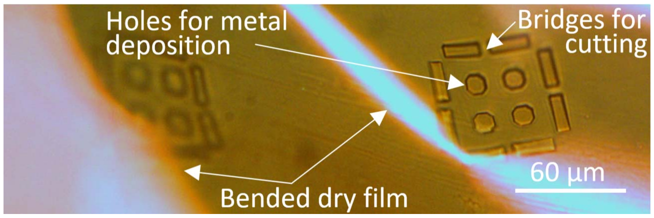


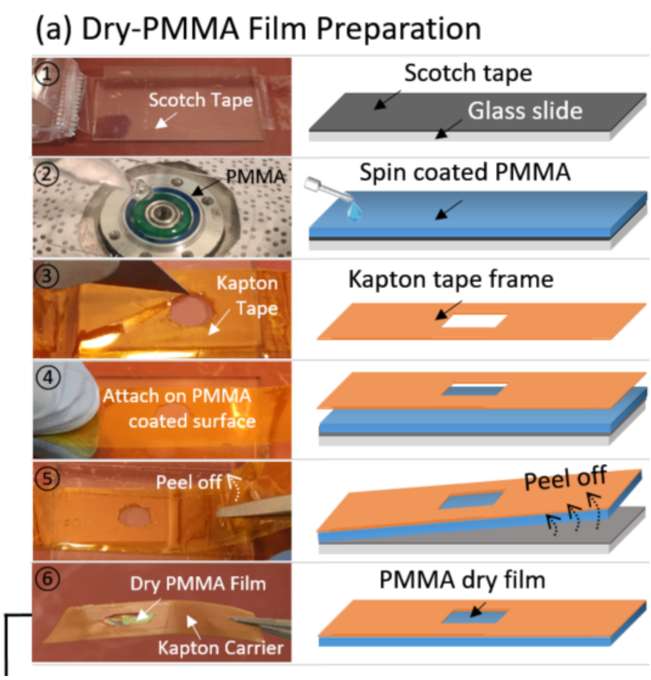
Figure2: Optical image of a pre-pattered PMMA film before transfer. Patterns on suspended dry-PMMA film are formed via electron beam lithography without contact to a base substrate. High contrast areas on the left and middle show bended film regions. Four holes in the center is designed to prevent cracks on the film due to a plastic deformation or a surface stress during EBL exposure and a development process [12].

EXPERIMENTAL METHODS

A detailed process flow is shown in figure 3. The process starts by the dry film preparation in fig. 3(a). Then, the latter half of the process is split into two methods of transferring; 1) pre-e beam in fig. 2(b), and 2) post-e beam in fig. 2(c) according to shapes of target substrates.

Dry-PMMA Film Preparation

Step ① in Figure 3(a) shows attaching the scotch tape (transparent, 3M) onto a clean glass slide. Bubble should be removed for uniform thickness of dry film ② The PMMA (950, A4, MicroChem) liquid is coated by spinning on the flat surface of the scotch tape. Parameters of spin coating are 2,000 RPM, 400 acceleration and 1 minute. Then, the slide is placed on a baking plate with 150°C for 4 minutes. ③ Next,



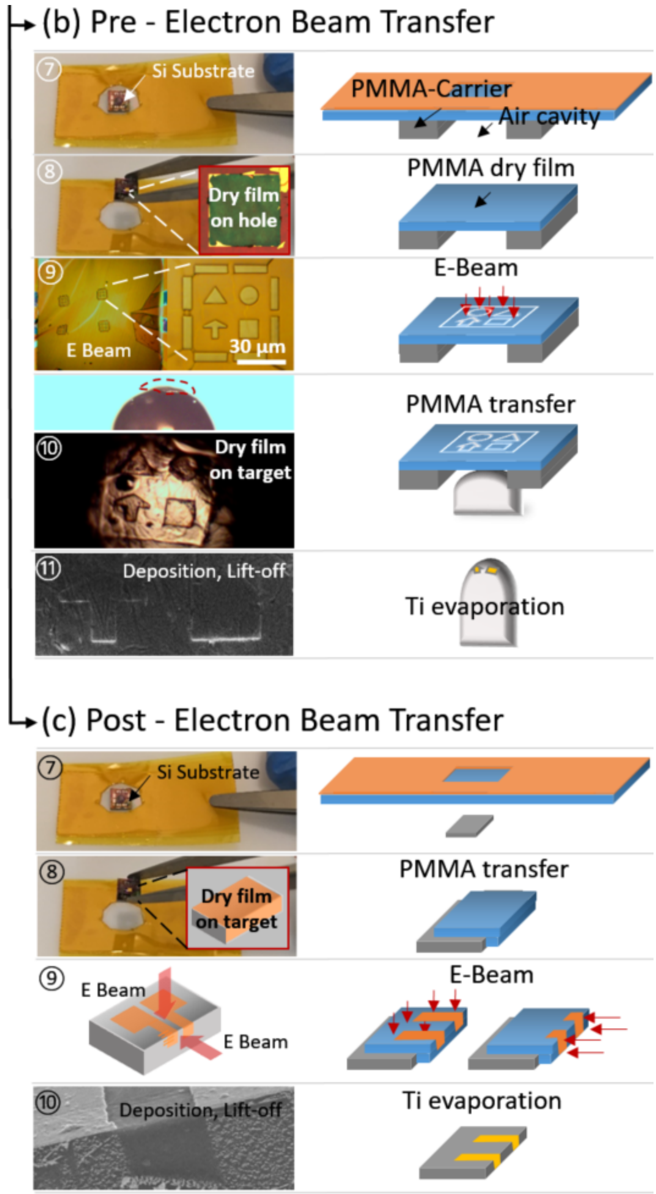


Figure 3: Process flow of a PMMA transfer. A suggested process is effective yet very easy to follow without using an expensive material or equipment. The process is categorized for 2 ways according to the shapes of target substrates. (b) A pre-E beam transfer method is appropriate to round or curved surface. (c) A post-E beam method is adequate for other non-flat like the edge or bridge.

the Kapton tape is attached onto another glass slide and a desired size of a window is cut in the middle of the Kapton tape. ④ Then the Kapton tape, as a dry film carrier, is re-attached onto the first glass slide that is covered by the PMMA film. ⑤ The Kapton tape carrier is peeled off smoothly. The carrier is required high stiffness for avoiding wrinkles on the PMMA film. ⑥ The dry-PMMA film is suspended inside the window frame of the Kapton. This film is ready to be transferred either to the target substrate via direct transferring.

Pre-Electron Beam Transfer Method

Pre-patterning of PMMA film is adequate where a post-transfer patterning is challenging such as rounded and curved substrates. We have successfully demonstrated the transfer of pre-pattered film on a needle tip and the detailed processes are shown in figure 3(b) and figure 4. Step ⑦ in fig. 3(b) describes that the dry film is attached onto a millimeter scale solid structure that includes hole. The hole supports the suspended film during the EBL and transfer process.⑧ Pick up the structure by tearing film near from the structure. The dry PMMA film should be located on the surface without deflection inside the hole. Then, the structure is baked on a hot plate at 130°C for 2 minutes. ⑨ Patterns are fabricated by EBL. After the exposure, the film is developed with MIBK/IPA (1:3, MicroChem) for 60seconds. The film is preferably placed perpendicular to developer surface to avoid crack propagation of the film due to surface tension between suspended film and liquids. ⑩ Top of the sewing needle lifts upward to mount the patterned dry film onto its top surface.

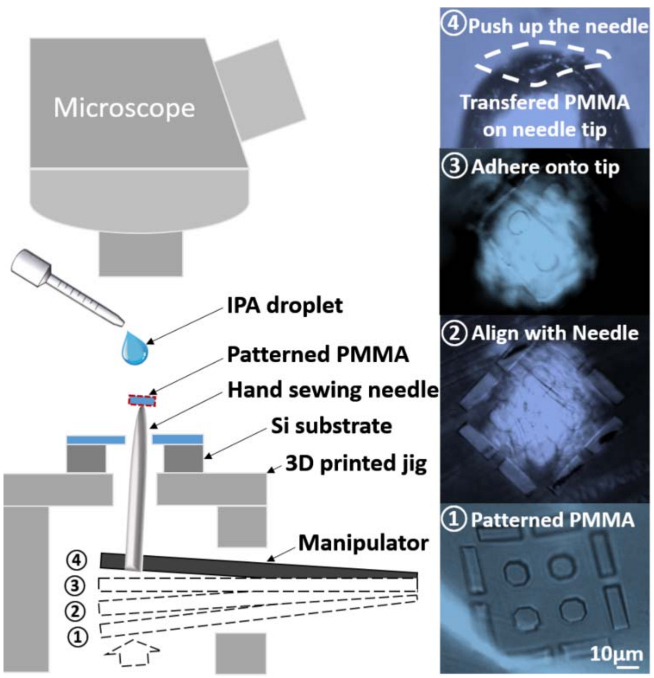


Figure 4: Conceptual image of assembly procedure between the patterned PMMA film and the sewing needle tip using microscope, manipulator, and a 3D printed jig [13]. *① 4-edges supported patterned PMMA film in room temperature and normal pressure. ② The needle tip approaches to PMMA. ③ The tip is contacted to PMMA. ④ The tip lifts upward the patterned target film.*

A simple probe station setup described in Figure 4 can facilitate the transfer. Dropping an isopropyl alcohol (IPA) onto the docking point enhances adhesion force, because there is no attractive force between dry film and dry needle. Even though the pristine PMMS surface is hydrophobic [14], the IPA droplet pushes the patterned dry film downward by its weight. The film can be adhered on the irregular surface without gap. Then, cutting bridges between the squares can be disconnected by pushing up the needle. ⑪ The needle is vertically hanged freely on a roof of sputter for a Ti deposition followed by a lift-off and an ultrasonic cleaning in acetone.

Post-Electron Beam Transfer Method

This process for transferring onto a flat surface or edge of the silicon wafer in the step ⑦ in fig. 3(c) shows that the dry film is attached onto a target substrate. This post-e beam method does not demand the small holed structure for lifting up. ⑧ Pick up the target silicon wafer by tearing film near from the target. ⑨ The EBL is performed on target position. ⑩ the metal pattern is remained using the lift-off after Ti/Au deposition via the metal evaporation.

RESULTS AND DISCUSSION

A presented process is versatile and can effectively generate nano- and micro-scale patterns on irregular and fragile substrates. In addition, the overall process is easy to follow at low cost. Upon completion of transfer, the dry-PMMA film performs as an effective mask layer for the lift-off process, thus metals or other materials can be sputtered or e-beam evaporated followed by lift-off. Figure 5 and figure 6 show the two types of practical applications. The pre-e beam process is appropriate to applications in figure 5 and 6 that have round/curved surfaces. Within technical limitation, a smaller dimension patterned film is easier to transfer onto target substrates. The post-e beam process is adequate for application that employs non-flat surface, edge, narrow and fragile structure. A detailed demonstration can be found in previous literature [8]. The suggested PMMA transfer process provides an unprecedented advantages for nano- and micro-applications.

Sharp Tip of Sewing Needle

A large array of a programable shape is transferred on the top of a sewing needle tip for demonstration. As discussed in previous section, low adhesion force between the tip and the dry PMMA film prevented the yield of the overall transfer process. As discussed in the previous section, the properties of IPA droplet, liquid and weight, play a key role by promoting adhesion between the film and the target surface.

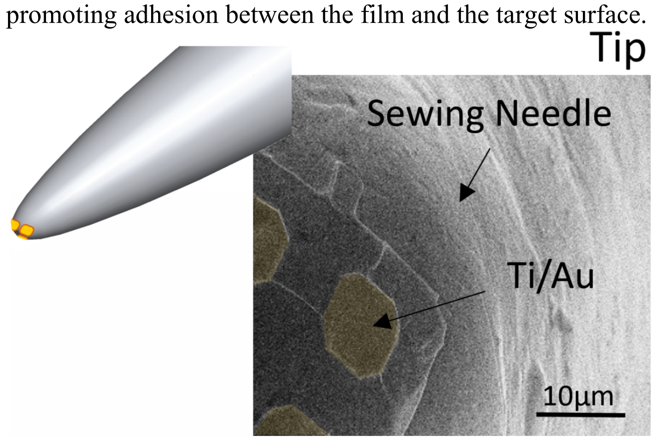


Figure 5: SEM image of pre-E Beam pattern on top of the

sewing needle. 10 μm ×10μm array patterns are made using the process.

Conical Surface

A more complex pattern, 'U of U' in figure 6 (it stands for the University of Utah), is designed and transferred on the top of a blunt tip surface. When the needle tip is lifted upward by a micro-manipulator, mis-alignment occurs between the center of the pattern and the top surface of a cone structure. Then, the half number of bridges are disconnected by the same method ⑩ in Fig. 3(c). After cutting bridges, pattern center must be moved to the side surface. Then, the needle tip is lifted upward again to cut the remained bridges. The pattern is located on the side surface of tip simultaneously.

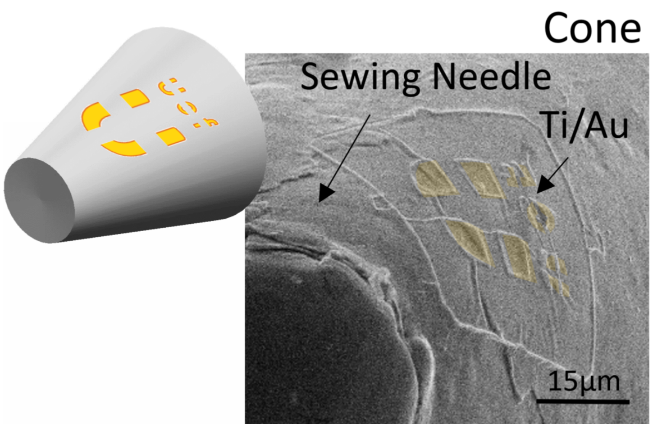


Figure 6: Pre-pattered U of U shape is transferred on the side wall of the probe tip. Yellow colored pattern in a square is 'U of U'.

CONCLUSION

This paper presents a novel yet simple dry-PMMA transfer process for e-beam lithography on a non-flat substrate. Transfer of a pre-pattered PMMA film on top of the needle is successfully demonstrated. The suggested technique is an easy process to follow without requiring expensive equipment or materials. Not only is it possible to make the patterns on irregular surfaces, but it also can be used to fix the patterns of various mis-shaped chips or narrow circuits.

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