A LIQUID-BASED GRAVITY-DRIVEN ETCHING-STOP TECHNIQUE AND ITS APPLICATION TO WAFER LEVEL CANTILEVER THICKNESS CONTROL OF AFM PROBES

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ABSTRACT

This paper mainly describes a liquid-based gravity-driven etching-stop technique used for cantilever thickness control of Atomic Force Microscope (AFM) probes on the wafer level. The technique makes use of the method of opposite etching trenches or the depth rulers. A pair of opposite trenches surrounds several AFM probes on both sides of the wafer to form probe chips. The trench depth on the cantilever front-side is equal to the designed thickness of cantilevers. In the final step of the fabrication process for AFM probes, the wafer is etched by the KOH etchant to form the probe handles. The probe chips will be separated from the wafer simultaneously with the penetration of wafers at the trenches. The separated probes fall into the Diiodomethane (CH_2I_2) solution beneath the KOH etchant and the wet-etching stops automatically. The cantilever thickness of the AFM probes can then be wafer-level controlled by the proposed etching-stop technique.

1. INTRODUCTION

The etching technique plays an important role in the MEMS processes. Especially, anisotropic wet etching is used in fabricating many MEMS devices such as sensors or actuators. These microstructures should be necessarily controlled with precise dimension for meeting the performance requirements of MEMS devices. Therefore, many methods involving etching-stop have been employed in fabricating microstructure, e.g., membranes and cantilever beams with proper control of thickness dimension crucially.

The thickness control or etch-stop methods for making silicon microstructures include p+ (heavily boron-doped) etching-stop in KOH [1]/ EDP [2], the electrochemical etching-stop for high-precision thickness control [3], and the etching-stop technique by SOI wafers [4]. Although these methods can be performed to obtain the microstructures with uniform thickness control, the technical barrier and the execution cost are still high. For this reason, this paper presents a simple and inexpensive technique of the liquid-based gravity-driven etching-stop for the well thickness control of membranes or cantilevers which are applied in AFM probes.

The mostly commercial AFM probes are made by p+ ion implantation technique [5] or SOI wafers [6, 7], matched with the anisotropic etching, to control the cantilever thickness. These methods are not only complicated, costly expensive and highly technical in manufacture, but also hardly have economic results of dimension control in rewards. Therefore, this paper shows a good result of AFM probes by the liquid-based gravity-driven etching-stop skill herein, and depicts the comparison with other previous techniques.

2. CONCEPTION AND PRELIMINARY RESULTS

In this paper, the concept of liquid-based gravity-driven etching-stop technique is combined with the opposite trenches, or the depth rulers [8] method into the MEMS processes to manufacture microstructures such as membranes or cantilever beams. The verification experiments of the conceptual stage of the whole research contain two parts, part A and part B. The part A is the search of the etching-stop liquid solution, and the part B focuses on the fabrication of opposite trenches in thickness control.

In the part A, the candidates for the etching-stop liquid solution of gravity-driven technique must satisfy three conditions. First, the etching-stop solution ought to stay below the anisotropic etchants like KOH and THAH (i.e., the density of the solution should be larger than the densities of KOH and TAMH) during etching. It doesn't allow obvious density change of the etching-stop solution subject to the external heating accordingly. Second, the anisotropic etchant can still be well temperature-controlled with the heating energy transmitted through the etching-stop solution from the bottom hot-plate. Third, the etching-stop solution must be chemically inert to silicon and the anisotropic etchant both. Based on the above mentioned considerations, a good etching-stop solution of Diiodomethane (CH_2I_2) is found out and applied to this research.

Figure 1 illustrates the preliminary result of etching and non-etching experiment in a heating process from room temperature to the boiling point of the etching solution. The etching solution KOH and the etching-stop agent CH_2I_2 were poured into the beaker together with a silicon strip immersed in this simple experiment setup. While the hydrogen bubbles appearing on the fragment of silicon strip clearly shows the silicon etching in KOH, there's no etching phenomenon for the silicon portion in the CH_2I_2 region on the contrary. Such a selective etching phenomena sustains for hours until the top part of the silicon strip is exactly etched away in KOH. Undoubtedly, CH_2I_2 is a competent, appropriate etching-stop solution in the

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liquid-based gravity-driven etching-stop technique.

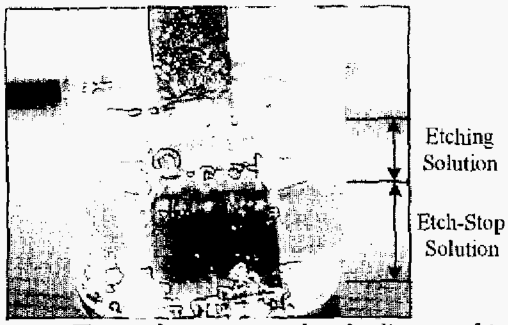

Figure 1: The preliminary result of silicon etching and non-etching experiment in a heating process. The etching solution is KOH; the etch-stop solution is CH_2I_2.

After the feasibility experiment of etching-stop solution was carried out, we integrated the opposite-trench or the depth-ruler technique into the membrane or cantilever beam thickness control in the part B. The fabrication process is shown in Fig. 2(a)-(c) and described in the following steps.

(a) The definition of cantilever beam or membrane: The process begins with growing a layer of silicon nitride on wafer, and the wafer is spin-coated with a layer of photoresist for the lithographic patterning. Sequentially, the silicon nitride film is patterned with reactive ion etching (RIE) to form the microstructure contours available for anisotropic wet etching afterwards. Additionally, the etching windows on the back side of wafer are defined by the double-sided lithography accordingly.

(b) The definition of opposite trenches: This step is an important key procedure for the good thickness control of microstructures because the final resulting thickness always depends on the depth of trenches (V-grooves) on the wafer front side. Therefore, the trench must be assigned around the micro device and the trench depth should be guaranteed as the precise thickness of micro devices (i.e., membranes or cantilever beams.) The alignment technique of defining crystalline orientation of silicon wafer subject to KOH etchant is necessary herein.

(c) Structure release: The Teflon etching-stop holder is used to achieve the microstructure thickness control as shown in Figs. 2(c) and 3. The device of cantilever beam was released from the handle frame in the moment of opposite trenches met with each other. In other words, when the etching solution KOH penetrated the wafer at the opposite trenches during the backside etching process, the micro devices were simultaneously separated from the wafer substrate and fell into the etching-stop solution CH_2I_2. The cantilever beams or membranes with the good thickness control were then safely preserved and automatically etched-stop.

The good thickness control of cantilever beam was achieved as Fig. 3. In the Fig. 3 (a), it clearly showed that the bubbles still appear at the KOH region but the released device hasn't etching bubbles anymore in the CH_2I_2 region.

The device of cantilever beam in Fig. 4 shows the long and uniform microstructure successfully made by this novel etching-stop technique in practice. Moreover, this technology not only applies to the case of a single micro device, but also suited to the fabrication of a micro array with adjusting the etching contours or layouts consequently.

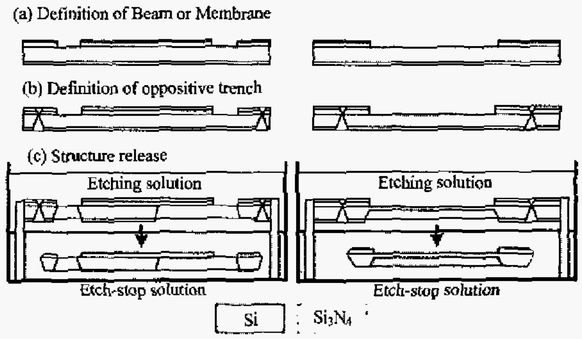

Figure 2: The fabrication and thickness control processes of microstructure: (a) the definition of microstructure; (b) the manufacture of opposite trenches for the thickness control; (c) the device release with thickness control technique.

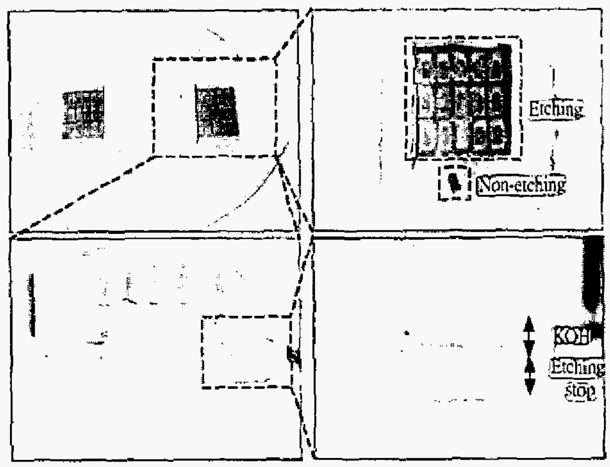

Figure 3: The experiment of liquid-based gravity-driven etching-stop technique: (Above :) the top view; (Below :) the side view of the etching-stop experiment.

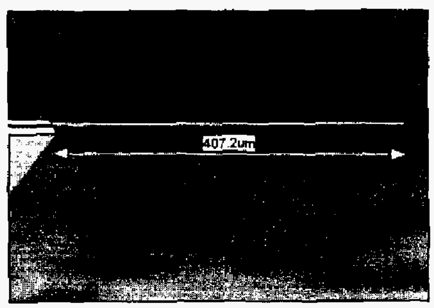

Figure 4: The single device of a cantilever beam of 2μm thick, 407.2μm long.

3. THE APPLICATION OF THICKNESS CONTROL TECHNIQUE TO AFM PROBE'S BEAMS

Many AFM probes are manufactured by the wet etching technique of silicon buck micromachining, and the beam thickness of the AFM probes needs to be controlled well by etching-stops. For the excuse of the beam thickness affects the measurement resolution, we therefore applied the novel etching-stop herein for the manufacture of AFM probe array shown in Fig. 5. In this case, we imitated the preliminary experiment of single micro device with a cantilever into the configuration of a 3×5 AFM probes array. It means that many dummy device about the opposite trenches on the substrate need to be repeated and duplicated. Additionally, the procedure for making AFM nano-tips should be augmented and inserted into the whole process compatibly.

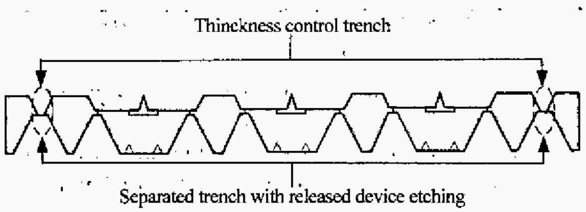

Figure 5: The cantilever thickness control of 3x5 AFM probes array by liquid-based gravity-driven etching-stop technique.

Fig. 6 shows the modified processes flow, which integrated the etching-stop technique of micro-cantilevers as well as process of the nano-tips for the manufacture of AFM probes. The whole process is composed of the manufacture of conventional AFM nano-tips and the thickness control trenches for AFM probe-array chips released by gravity-driven etching-stop technique. Restated, the silcon substrate must be verified with its crystalline orientation accurately before the device manufacture, and let the orientation become a standard guideline for the following manufacture process. In doing so, it can avoid any negative influences on the AFM probe's dimension.

Figures 6 (a)-(c) show the manufacturing procedures of the probe's nano-tips as well as the cantilevers with thickness-controlled trenches. (a) The process begins a 4-inch silicon wafer with a LPCVD silicon-nitride film of 4000 Å thick, film. The cantilever beam and thickness control trenches, which depth is approximately 4.1~ 4.5μm, are made by photolithography, RIE and KOH etching (45 wt% and 75℃.) (b) The silicon nitride film of 4000 Å thick, is patterned into squares that act as a mask against KOH of 45 wt% at 75℃ to form silicon pyramids. (c) The apex of the pyramids is sharpened by thermal re-oxidation and the silicon nitride is deposited once again as the protection layer.

Finally, Fig. 6 (d) illustrated the thickness control and the release processes. This part focuses on the AFM probes array chip releasing by KOH backside etching and the gravity-driven etching-stop skill. Continuously, the silicon nitride film being patterned by the lithography and dry etching, the probe handle base were formed and separated from the backside at the trenches. Somewhat different from the previous section about micro cantilevers, the trench depth now is not necessary to be defined, and it only depends on the etching of probe handle and tied with the liquid-based etching stop technology. Finally, the probes array chips drop into the etching-stop solution when the controllable trenches work.

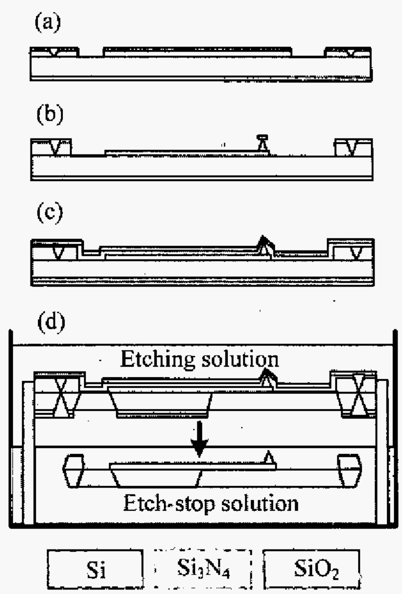

Figure 6: The detailed fabrication and thickness control process of the silicon-based AFM probes array: (a) the cantilever beam and thickness control trenches fabrications; (b) the squares silicon nitride act as a mask against an anisotropic etchant of KOH; (c) The apex of the pyramids are sharpened by re-oxidation and protection layer deposition; (d) the probes array chip released with the gravity-driven thickness-controlled technique.

4. RESULTS AND DISCUSSION

By the above manufacture process, the 3 x 5 AFM probe-array chips are fabricated and shown in Figs. 7 (a)-(c). Fig. 7(a) shows the whole chip of 3x5 AFM probes array. Fig. 7(b) is the SEM picture of AFM probe array. Fig. 7(c) presents the magnified image of an AFM probe of 4.27 μm thick and 125 μm long. Finally, from the revelation of uniform cantilever beams depicted in Fig. 7, it verified that the technique of liquid-based gravity-driven etching-stop for wafer lever's probe manufacture functions very well.

Figure 8 illustrates the dimension deviation of the proposed thickness of cantilever beams with respect to the depth of controlled trenches by the liquid-based gravity-driven etching-stop technique. There are five data of controlled trenches in this comparison figure and all the AFM probes were picked up from sixteen probes array chips on a 4-inch wafer. The solid line represents the etching depth in the controlled thickness trench that dominates the over thickness of cantilever beam; the dotted line indicates the finished thickness values of AFM probes. A dimension error of 2.94 % is measured between the proposed cantilever beam thicknesses value and the trench depth value. Consequently, it proved that the liquid-based gravity-driven etching-stop technique can fabricate the AFM probe array on the wafer level, and quite accurately control the AFM probe thickness at the same time. There's no other control way of AFM probe arrays that have heard and achieved to full wafers so far.

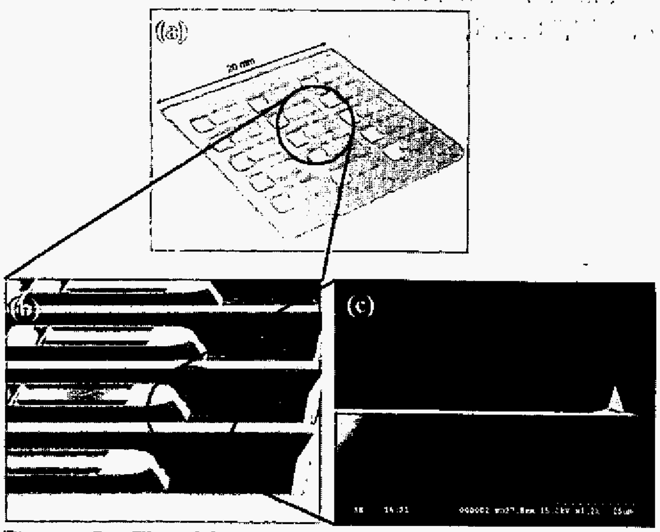

Figure 7: The fabricated AFM probe chip using the liquid-based gravity-driven etching-stop technique: (a) a chip of 3×5 AFM probes array; (b) the SEM picture of AFM probe array; (c) the single probe of 4.27μm thick, 125μm long.

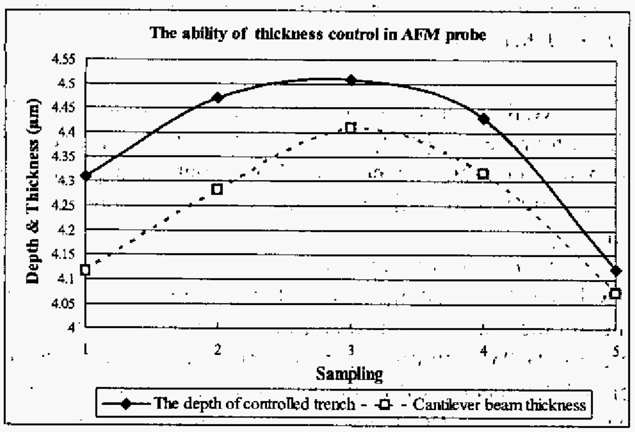

Figure 8: The dimension deviation of the proposed thickness of cantilever beam with respect to the depth of controlled trench.

5. CONCLUSIONS

In summary, the performance of liquid-based gravity-driven etching-stop technique with the help of opposite etching trenches was verified and this control method is used to fabricate AFM probe array in this paper. Furthermore, this novel method for AFM-probes manufacture is simple and inexpensive because it makes use of the etching-stop solution of Diiodomethane (CH_2I_2) to achieve the thickness controlled by the gravity-driven mechanism. In technical barricade, its ease depends on the opposite trenches to accomplish the thickness control in the cantilever beam of AFM probe. In addition, this technology had an advantage of the microstructure controlled on the wafer level. Because it needs only change the layout about the opposite trenches on both sides of the silicon substrate, this technology can be applied from the case of a single micro cantilever to AFM probe-array chips. We believe that this concept of liquid- based gravity-driven etching-stop technique with opposite trenches is a useful, economical method for controlling other microstructures in MEMS fields.

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