Fabrication of Al-Si Thermal Linear Motors

Hoa T.M. Pham, Sander L. Paalvast, Pasqualina M. Sarro

Abstract— **In this paper, we present the fabrication process, specifically developed for the realization of a Thermal Linear Motors (TLM) with different configurations. Aluminum with a thickness of 5µm is used as an expansion element, while a 3µm – 5µm thick in-situ doped polysilicon is used as a heater. Several technical problems encountered during the preparation of these devices are discussed and solutions to address these issues are given as well.**

***Index Terms*— Thermal Linear Motor, Plasma etching, Wet etching, Deep Reactive Ion Etching (DRIE).**

I. INTRODUCTION

Thermal Linear Motors (TLM) for high thermal bandwidth and improved measurement sensitivity and controllability are of great interest for larger microsystems [1,2]. An aluminum Thermal Linear Motor (TLM) with an integrated polysilicon heater has the large force (5-25mN) and high power density typical for thermal actuators but at the same time has a very low thermal time constant (0.08-0.6ms). The aluminum TLM is the crucial driving element for a Hard Disk Drive (HDD) thermal micro actuator. It occupies less area than an electrostatic actuator with the same driving force while still reaching 3-5kHz bandwidth for positioning accuracy better than 5nm. By using aluminum for the expansion element, the power consumption of our motor is 3 to 9 times lower than that of silicon TLMs. The basic concept and the advantages of using these materials have been discussed in [3]. In this paper, we present the fabrication process, specifically developed for the realization of the TLMs with different configurations.

II. EXPERIMENTAL

TLMs with varying dimensions are fabricated on a silicon substrate. A set of only three masks is used to fabricate the TLMs. First, a 500nm silicon oxide (SiO_2) layer as an electrical isolation layer is grown on a silicon substrate by wet thermal oxidation. For the heaters, a thick layer of highly doped polysilicon is needed. The 3µm to 5µm thick polysilicon layer is epitaxially grown on a 20nm Low Pressure Chemical Vapor Deposition (LPCVD) polySi seed layer. The sheet resistance of the epi-poly is ~ 150Ω/sq. The in-situ doped epi-poly is patterned to form the heaters using RIE based on fluorine gas plasma. Next a 5µm thick layer of aluminum is sputtered and patterned. Both wet and dry etchings are used to shape the aluminum parts of the motors and to remove the aluminum fence occurring at the edge of the thick polysilicon layer. An alloy step is needed to stabilize the devices. Figure 1 show the schematic flow used for fabrication of the TLM.

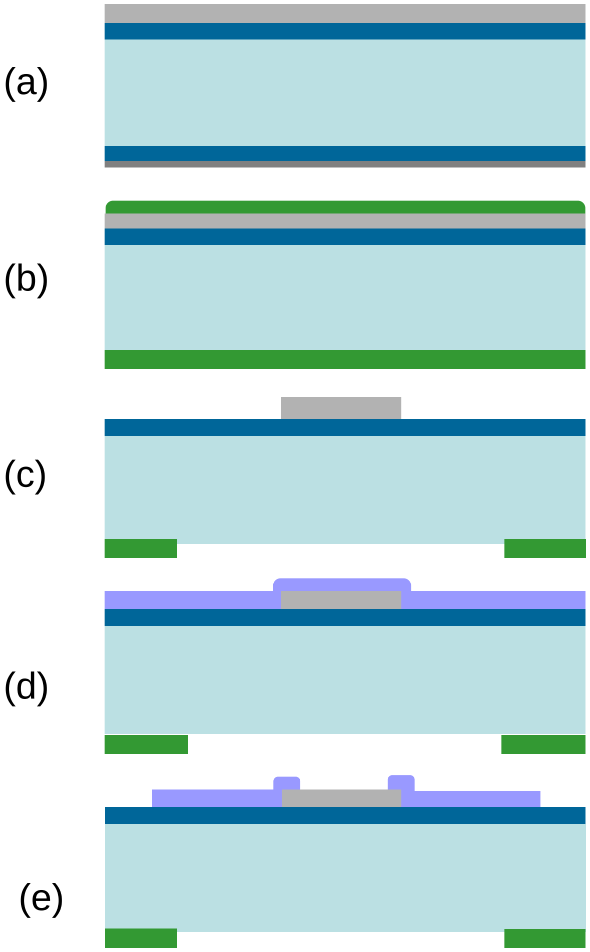

Fig.1: Schematic process flow for the fabrication of the TLMs

The motors are then released by selectively removing the silicon substrate from the backside. Either a wet chemical (KOH) etchant followed by a short dry etch step or directly Deep Reactive Ion Etching (DRIE) are used.

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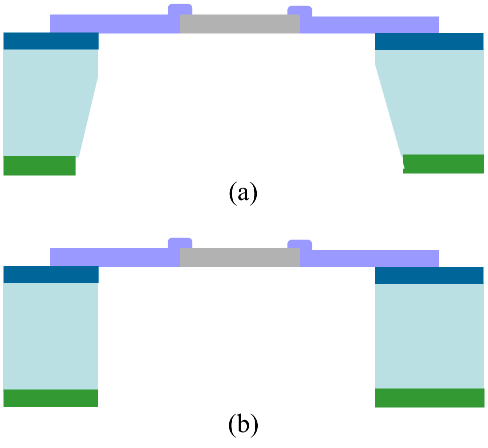

Fig.2. Comparison between KOH and DRIE etching

In the first case a 300nm silicon nitride (SiN) prepared by LPCVD technique is used as masking layer. When DRIE is employed, then a 6µm silicon oxide layer prepared by Plasma Enhanced Chemical Vapor Deposition (PECVD) is used as hard mask.

III. RESULTS AND DISCUSSIONS

Figure 3 shows the different heater configurations, a) pure aluminum, b) edge heaters, c) central heater, that are evaluated. The relevant design parameters are: length 200 ÷ 600µm, width 5 ÷ 40 µm, thickness 5 µm, heater length 5 ÷ 20 µm.

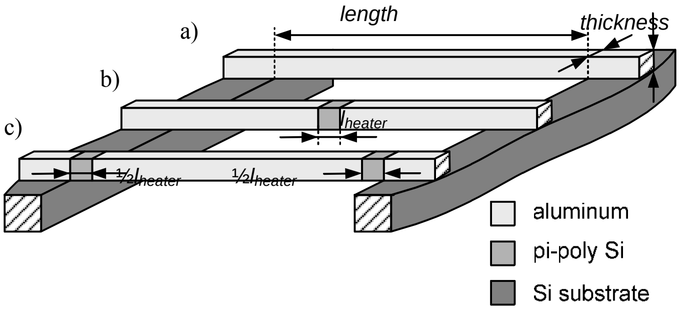

Fig. 3: The TLM configurations evaluated: a) Aluminum TLM, b) with silicon heater in the center, or c) at the edges

Figures 4a and b are SEM images of TLMs, with varying width. In the close-up, figure 4b, the silicon heater is clearly visible in the center of the motor. The characterization of these devices is reported in [3].

Based on measurement results, the fabrication process has been modified to improve the quality of the devices. A 3µm – 5µm polysilicon layer used as heater can be etched either by RIE or DRIE. The DRIE can give more uniform etching on the whole wafer due to the much higher etch selectivity of polysilicon versus SiO_2. However, the process time is longer compared to RIE.

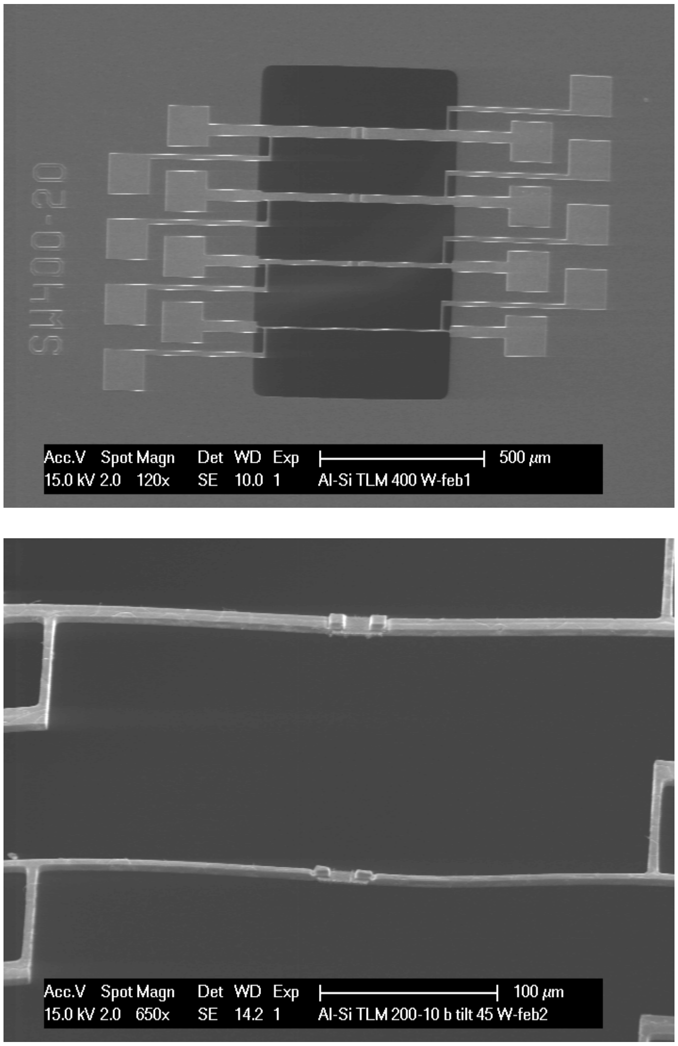

Fig. 4: SEM images of TLMs with different configurations.

The most critical step is patterning the 5µm thick Al layer on top of 5µm polysilicon. Thickness control of the photoresist mask is very important for this step. The uniformity of the photoresist layer is very poor where the aluminum goes over the thick polysilicon. Figure 5 shows the aluminum being damaged when the thickness of the photoresist is not enough. This leads to poor mechanical and electrical contact between the aluminum and the polysilicon as observed during the first evaluation.

Calculation shows that the photoresist thickness should be 2µm to protect the aluminum at that point, so the nominal thickness of photoresist should be about 6µm. However, if the photoresist is too thick, it will stay at the edge around the polysilicon islands, making it very difficult to expose and develop the photoresist. An aluminum ring around the polysilicon appears causing a shortcut of the heater (see figure 6).

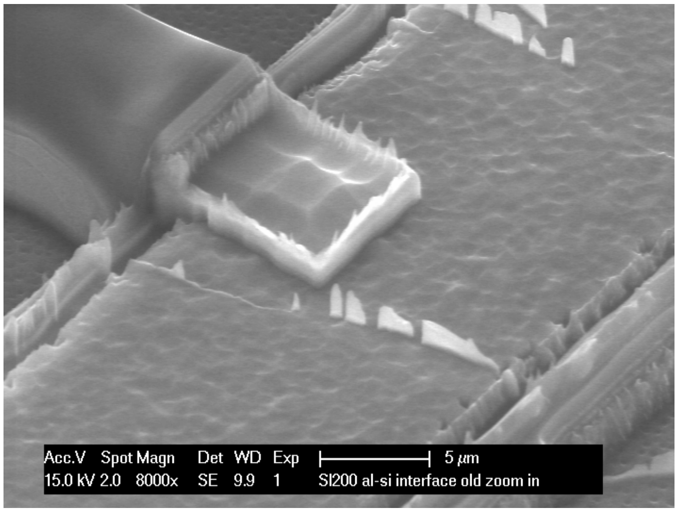

Fig. 5: Aluminum is attacked when the thickness of photoresist at the highest point is not sufficient.

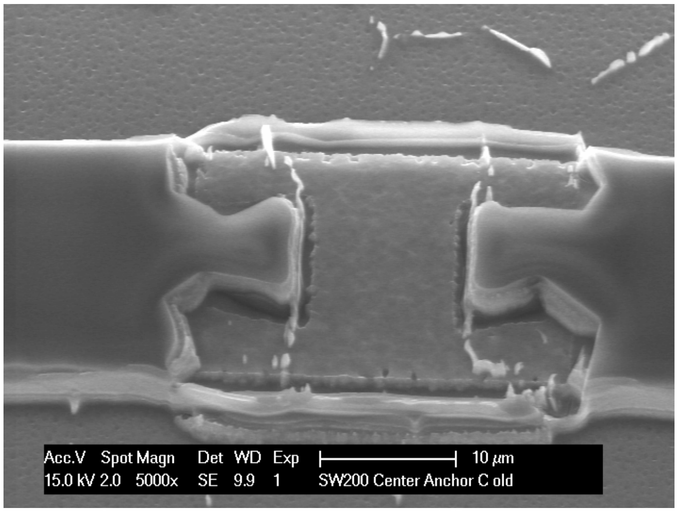

Fig. 6: A ring appears when photoresist stays at the edge of the polysilicon.

To reduce this aluminum ring, the energy during exposure is increased up to 1000mJ. After dry etching, an extra wet etch is performed to completely remove the aluminum sidewall. Due to the very small selectivity between aluminum and polysilicon the dry etching is just stopped before all the aluminum is etched from the polysilicon. The remaining very thin layer of aluminum is removed by the wet etching. As the aluminum is isotropically etched, the aluminum on the side is etched as well during this wet etch (see figure 7). To obtain the desired width, this under etching must be taken into account when designing the masks.

Besides increasing the photoresist uniformity the thickness of the polysilicon layer was reduced to 3 µm to improve the step coverage of the aluminum on the polysilicon.

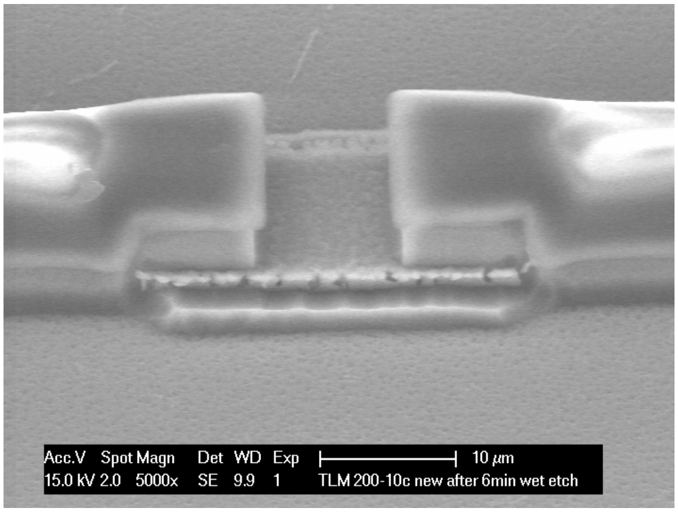

Fig. 7: A 5µm aluminum etched isotropically on the side when removing the aluminum ring.

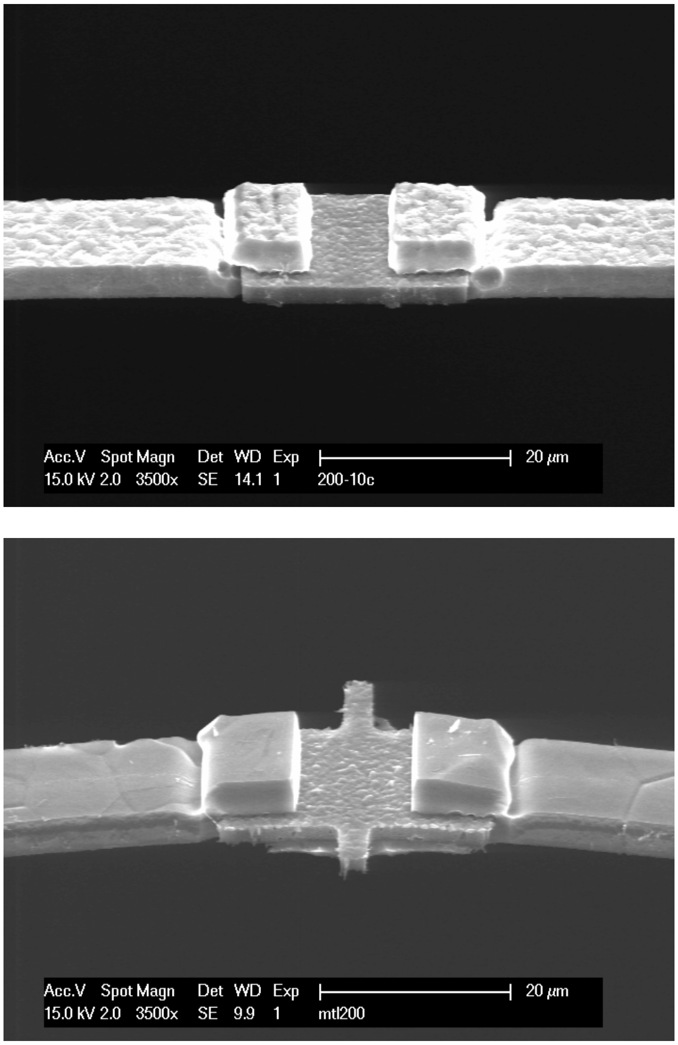

Fig. 8: SEM images of the contact between aluminum and polysilicon.

SEM images in figures 8a and b are close ups of the contact between aluminum and polysilicon. A new way to pattern polysilicon is then applied to further improve the aluminum and polysilicon contact. The anisotropic etching characteristic of DRIE results in vertical polysilicon walls. A modified etching recipe is used to obtain slanted walls resembling the one obtained using KOH etching.

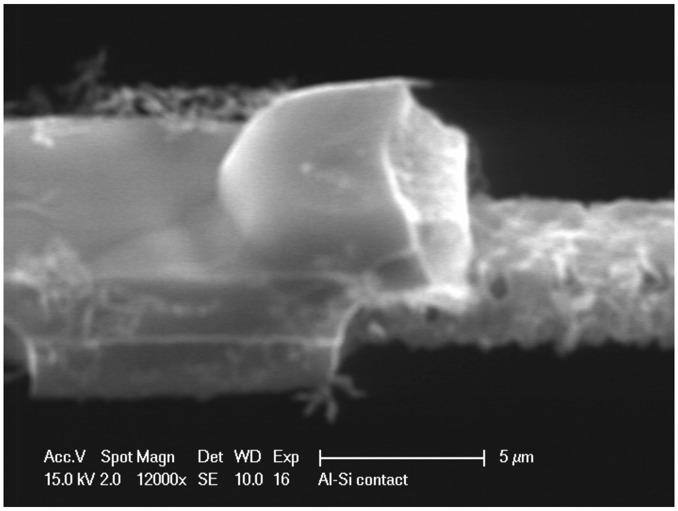

Fig. 9: Contact between aluminum and polysilicon patterned using the modified DRIE process.

Figure 9 shows the contact between aluminum and polysilicon patterned with this more isotropic process. Another advantage of this method is that no aluminum ring remains during the aluminum etching.

IV. CONCLUSION

In conclusion, a well controlled process that allows the fabrication of the Al-Si TLMs has been developed. The fabricated TLMs will be employed as driving element of a microactuating system to improve the positioning accuracy of the Hard Disk Drive read-/write-head.

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