

IMPROVED REGISTRATION TECHNIQUE FOR FABRICATING THICK-FILM PIEZOELECTRIC SENSORS

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Abstract: A fundamental limitation of screen printing is the achievable alignment accuracy and resolution. This paper presents details of a thick-resist process that improves both of these factors. The technique involves exposing/developing a thick resist to form the desired pattern and then filling the features with thick film material using a doctor blading process. Minimum feature sizes of $<40\mu\text{m}$ have been achieved with a film thickness of $100\mu\text{m}$. Registration accuracy is comparable to standard photolithographic processes.

Keywords: PZT, Doctor Blading, Thick Photoresist.

INTRODUCTION

Screen printing thick-film lead zirconate titanate (PZT) has been applied to MEMS in such applications as micropumps [1-3], accelerometers [4] and resonant sensors [5]. The approach is attractive since it is a simple, low-cost process for depositing thick layers of piezoelectric material in the desired pattern. However, the process is fundamentally limited by the resolution (minimum feature size typically $>100\mu\text{m}$) and alignment accuracy ($\pm 50\mu\text{m}$) achievable, compared to micromachined structures defined using standard photolithographic techniques. Print misalignments can affect device performance considerably, since optimum electromechanical coupling relies upon correct positioning of the piezoelectric element.

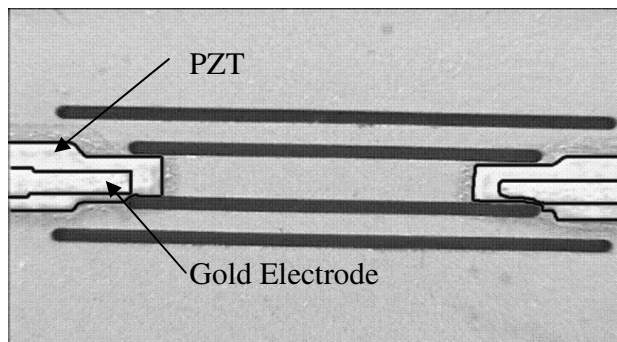


Figure 1. Poorly aligned screen print of PZT and top electrode on a resonant silicon sensor.

The issues of misalignment are demonstrated in the case of a resonant sensor with PZT actuation and pickup, shown in figure 1. The PZT is offset to the left and the top electrode to the left and down. The net effect of this is a reduced Q-factor, inefficient excitation and reduced vibration detection signal. This example highlights the need for a process capable of improved alignment.

The use of thick photoresist as a micromould has been documented for applications such as electroplating [6, 7] and advanced packaging [8]. This approach provides the alignment accuracy and resolution associated with optical lithography. This paper introduces the technique of doctor blading screen printable piezoelectric pastes into thick resist moulds, providing improved alignment accuracy and resolution over the conventional approach.

A key attraction to screen printing is the thickness of the deposited paste, which can be up to $100\mu\text{m}$. In the case of active materials, increased thickness can significantly improve the performance in many actuating applications. Therefore a resist-based patterning process must be capable of producing a minimum feature size of ideally $<50\mu\text{m}$ with a resist thickness of $100\mu\text{m}$. A second requirement is that the resist must be able to withstand the temperatures (150°C) used to dry the paste. Once the paste is dried, the resist must be easily removed from the substrate whilst leaving the dried deposited material in place. This paper presents an investigation into the suitability of four resists, two positive (Shipley SPR220-7, Clariant AZ9260) and two negative (Ordyl AM150, BPR-100). SU-8 resist has been evaluated previously and was found to be too difficult to remove from the wafer for this application.

EXPERIMENTAL PROCEDURE

Three of the four resists are liquid and can be applied by spin coating on a silicon wafer. Manufacturer specifications for spin speed, duration, number of coats and baking time were followed initially and subsequently adjusted to provide the required thickness. The third (Ordyl AM150) is a dry resist and can be applied by laminating the silicon wafer. A test pattern was then exposed using a Hybrid Technology Group (HTG) contact aligner with a UV light source ($350\text{-}450\text{nm}$ spectrum mercury lamp) at 3.1mW cm^{-2} . Where necessary any edge bead from the resist spinning process was removed to

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	SPR220-7	AZ9260	BPR-100	Ordyl AM150
Application	30 seconds @ 500 RPM 30 seconds @ 650 RPM Softbake 100°C for 15 minutes, ramp from 60°C for first layer.	10 seconds @ 500 RPM 20 seconds @ 900 RPM Softbake at 95°C for 4 minutes – layer 1, 100°C for 10 minutes – layer 2, 100°C for 15 minutes – layer 3.	10 seconds @ 500 RPM 30 seconds @ 800 RPM Softbake at 100°C for 7 minutes.	Laminated at 115°C and roller speed 0.15m min ⁻¹
Application Cycles	3	3	1	2
Attained Depth	100µm	100µm	100µm	100µm
Exposure	500 seconds Develop 100 seconds	650 seconds	330 seconds	40 seconds
Develop	4min Then 2min	6 minutes @ 25°C	Untried	3min

Table 1. Optimized parameters for photoresists

ensure good contact between the mask and wafer. Again manufacturer specifications were initially used for exposure and development duration and were subsequently adjusted.

The resists were evaluated using an Alpha-Step 200 surface profiler and optically inspected with a microscope and a Hitachi FEG-SEM. At this stage the wafers were ready for doctor blading.

The doctor blading process involves smearing the paste across the wafer, drying the paste, removing the resist and firing the paste as shown in figure 2.

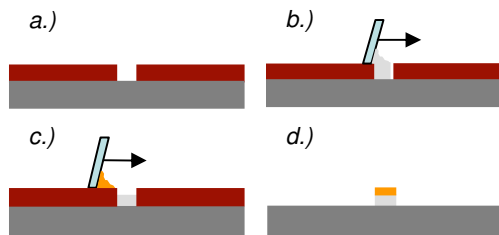


Figure 2. Doctor blading PZT paste onto wafer. a.) Resist with patterned features. b.) Doctor blade PZT paste across wafer. c.) Dry PZT, shrinkage leaves space to doctor blade top electrode. d.) Dry electrode, remove resist then fire.

The PZT thickness can be increased by re-blading another layer of PZT after the first drying stage. This can only be performed providing enough space remains for the gold to be deposited on top. The amount of PZT shrinkage during drying is determined by the make up of the paste; a mixture of glass, milled PZT and a pine oil vehicle [9]. More pine oil creates a less viscous paste which flows into the features more readily but has a high degree of shrinkage.

Once the PZT and gold have been deposited the resist must be removed before firing.

RESIST EVALUATION

Table 1 shows the optimised parameters used to assess the four resists.

SPR220-7 is not designed for thick resist applications but was included in the experiment as it is a readily available resist with known processing parameters. Using three layers applied at low spin speeds achieved a depth of 100µm. At this thickness the resist was approaching, if not exceeding, the limits of its use. Removal of the resist proved problematic at this depth. This was partly due to the pigmentation of the resist being too high therefore limiting the amount of UV light reaching the bottom of the features during exposure. This necessitated multiple exposure/develop cycles hence reducing resolution and registration of the features. Any resist remaining in the bottom of the features renders the wafer useless for doctor blading as it prevents the deposited paste from bonding to the substrate. The resist also proved sensitive to the temperature used for drying the paste: slight bubbling and reflow were observed. Therefore SPR220-7 was judged not to be a viable resist for the process.

The dry film nature of the Ordyl AM150 resist meant that a thickness of 100µm could be guaranteed with two applications of the 50µm thick film. The dry film resists are very consistent which leads to a high level of repeatability in the process. This resist produced excellent results as shown in figure 3. Features demonstrated vertical sidewalls with no resist residue visible on the surface of the wafer. Removal of the resist, though, proved to be much less straightforward than its application. As the paste was dried, the elevated temperatures caused the resist to harden. It became insoluble to solvents and KOH which meant it could not be removed without causing damage to the doctor bladed paste. Inability to remove the resist meant that the resist wasn't suitable for use in the process.

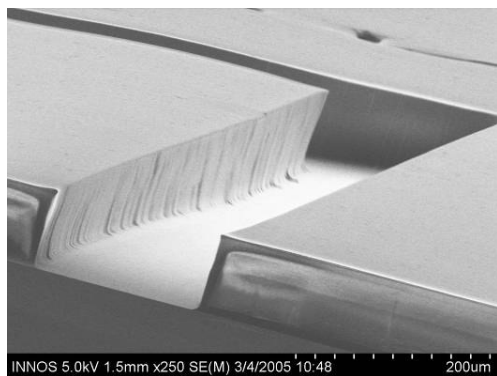


Figure 3. SEM photograph of Ordyl AM150 trench.

BPR-100 is a high viscosity resist and was found to be unsuitable for application using the equipment in our clean room. The resist is designed to be applied using a pump to control flow rate and prevent air from entering the system. Achieving an application with no bubbling using a pipette or pouring the resist, was impossible. As a result, the resist was not level across the wafer therefore reducing the effectiveness of contact exposure. This could not produce high definition features required by the process specification without investing in further equipment to apply it.

Finally, for the AZ9260 resist the target depth of 100µm was attained by applying 3 layers with a 900 RPM peak spin speed. The resist was allowed to settle for 8 minutes before soft baking at 90°C for the first layer then 100°C for the last two. The delay between spinning and softbaking prevented the resist from blistering and pulling in on contact with the heat. This lead to a well formed 100µm resist layer with very few defects. The lighter colouring of AZ9260 gave good transmission of the UV energy during exposure [7] meaning that a single exposure and development solution was possible. The optimised parameters proved to be a 650 second (2015mJcm⁻²) exposure and a 6 minute development in a 25°C bath of AZ400K developer mixed 1:4 with deionised water. The development stage was very sensitive to temperature and agitation but excessive agitation had to be avoided over development traits such as non-vertical sidewalls.

AZ9260 proved to be the most suitable resist for the doctor blading process as it was capable of producing the resolution and depth required and able to withstand the drying temperatures.

RESIST REMOVAL

Initial tests evaluated the use of solvents, such as acetone, to remove the resist. It was found that once the resist became sufficiently thick (above 60µm) the time taken for the solvent to remove the resist allowed the solvent to damage the PZT features.

Shorter immersion times with drying intervals between were evaluated but the solvent could not be driven from the features fast enough to prevent damage.

The use of KOH as an alternative was evaluated and proved feasible. A 4% KOH solution (10g KOH crystals in 250ml DI water) at 35°C removed the resist in 2 minutes though caused slight damage to the features. By splitting the process into two 1 minute immersions with a deionised water rinse and infra red dry between stages the resist was removed without damaging the features. The wafer could then be fired to sinter the paste.

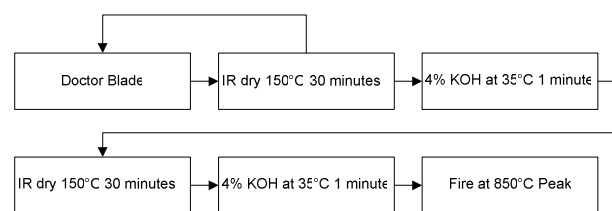


Figure 4. Doctor blading and resist removal process

RESULTS

Initial results from doctor blading a single layer of paste onto the wafers prove the feasibility of the process. Figure 5 shows a shouldered beam of PZT with good paste cohesion and a resolution of less than 40µm.

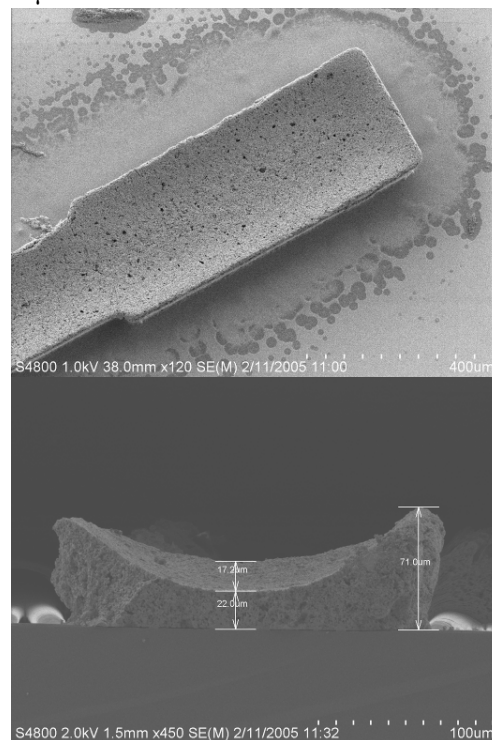


Figure 5. SEM photograph showing shouldered beam of printed PZT.

It can be seen that the beam is only 22 μ m high in the centre and 71 μ m at the sides. Though this leaves a good trench for gold deposition, piezoelectric performance of the beam will be limited by the lack of active material.

The addition of a second PZT blading step increased the depth of the deposited beam as expected but resulted in cracking of the beam. The cause of this cracking was attributed to the amount of vehicle in the paste. During drying the vehicle evaporates to leave the PZT and glass particle deposit. As the deposit becomes thicker a larger amount of vehicle must escape during drying thus leaving voids and cracks in the beam.

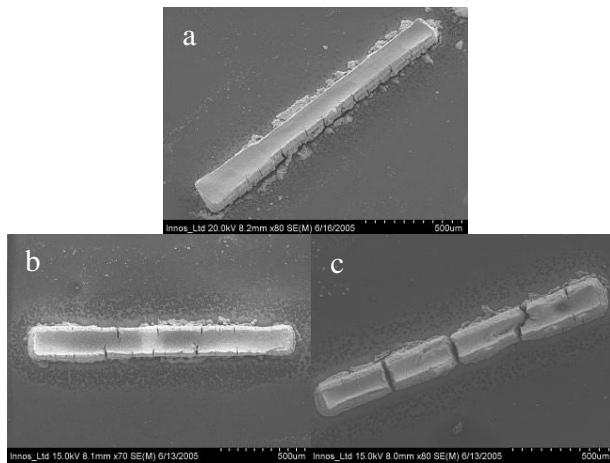


Figure 6. SEM photographs of varying paste viscosities: a.) High viscosity. b.) Medium viscosity. c.) Low viscosity.

This was evaluated by using three pastes of different viscosities: high viscosity (45 PaS), medium viscosity (25 PaS) and low viscosity (17 PaS). The results of the tests are shown in figure 6. It can be seen that the paste with the highest viscosity performed best, giving the least cracking.

The drawback of using a high viscosity paste was the reduced flow of the paste. This had the effect of reducing the quality of the contact between the paste and the substrate as the paste did not flow freely to the bottom of the feature. The reduced contact area will have a significantly detrimental effect on

performance and in a worse case cause the feature to become completely detached from the substrate. Work is now being conducted into how best to achieve a good contact between the paste and the substrate. Methods to be investigated include ultrasonics and using isostatic pressing to force the paste against the substrate prior to firing.

CONCLUSIONS

A process has been developed that is capable of depositing thick-film material with resolution and alignment accuracy comparable to standard photolithographic processes. The technique will be applied to deposit actuating and detecting elements onto a silicon resonating triple beam pressure sensor.

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