LOW-COST NANO-MANUFACTURING OF SURFACE ACOUSTIC WAVE DEVICES BY USE OF JET & FLASH NANO IMPRINT LITHOGRAPHY

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ABSTRACT

A nanoimprint lithography technique has been used to developed a SAW manufacturing technique, which can reduce the fabrication tolerances by a factor 10, paving the way for low noise communication components and calibration free sensors. The technique utilizeses Jet and Flash Imprint Lithography (J-FIL), which is a UV step and flash nanoimprint technique. Through this technique combined with an optimized dry etching development and lift-off process, metallic interdigitated transducer structures with feature variations less than 5 nm are demonstrating, showing the high fidelity patterning capabilities of the J-FIL technique. The end goal is to demonstrate a full pilot production with fabrication tolerances below 10 ppm, which will pave the way for cheap, high performance SAW components for the next generation.

Keywords: surface acoustic wave devices, nanoimprint lithography, jet and flash imprint lithography

1. INTRODUCTION

Surface acoustic wave (SAW) devices have many applications and can be found in common consumer electronics such as mobile phones, WiFi and GPS. Beside its use in electronics they can also be used as a passive wireless sensor [1,2,3]. For all applications it is a challenge to fabricate the devices with sufficiently low tolerances to reduce noise for filter/oscillator applications and to make calibration free devices for sensor applications. Commercial SAW devices are limited by the optical lithography which is only possible to make devices with a frequency dispersion of 150 ppm[4]. The goal is to develop a cost-effective, high throughput nano-manufacturing line based on Jet & Flash Nano Imprint Lithography (J-FIL) to reduce the frequency dispersion to less than 10 ppm. J-FIL has the advantage of being able create an almost perfect replica of a pre-fabricated stamp on the wafer. The stamp can be created using precision lithography techniques, which can fabricate lower tolerances and these fine structures can then inexpensively be transferred to the wafer[4].

2. J-FIL PROCESS

In J-FIL, a transparent Quartz template, having pre-defined nanostructures corresponding to the design, is used for pattern transfer. The first step is to dispense a drop pattern of low viscosity imprint monomer resist onto the substrate, corresponding to the template design figure 1(a). The drop pattern and volume is optimized to fit the specific imprint pattern. The template is brought into soft contact with a monomer resist which has been dispensed onto the substrate wafer. Capillary forces fill the template with the monomer resist while the template is moved towards the substrate stopping at a separation of tens of nanometers figure 1(b). UV light is used to expose and harden the resist figure 1(c). The template is separated from the exposed monomer resist and the template is stepped to a new location and the process is repeated figure 1(d). The main advantage with J-FIL, compared to other nanoimprint technologies, is that since it is a room temperature/low pressure process, thus any substrate can be imprinted. This is especially needed for SAW devices, which use fragile crystal substrates, such as quartz and lithium niobate.

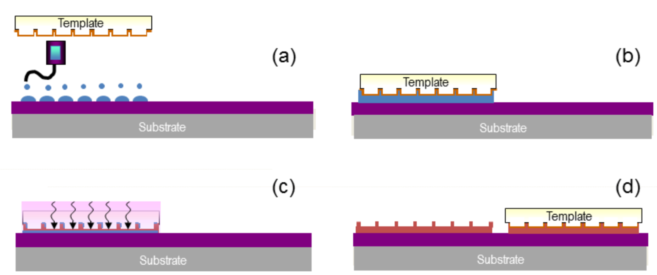

Figure 1. Schematic illustration of the J-FIL patterning technique.

3. SAW FABRICATION

The fabrication process flow for the SAW devices is shown in figure 2 and is explained in more detail in earlier work[4]. First a planarization layer is spun onto the substrate. In this case a SF5S from Microchem SF series has been used with a target thickness of 150 nm. In figure 2(b) the J-FIL imprint process is performed, which results in an imprint monomer (Silmat) resist pattern corresponding to the SAW structure. In figure 2(c) the residual monomer layer (usually approximately 10 nm thick) is removed in a dry halogen based etch, which also forms a thin silicon oxide layer on the silicon containing imprint monomer, which makes it resilient to oxygen based dry etching. In figure 2(d) an oxygen based plasma etching is used to etch the planarization layer, also undercutting the imprint resist, forming an ideal lift-off resist structure. In figure 2(e) 100 nm Al is deposited using e-beam evaporation and finally in figure 2(f) the Al is lifted off in Microprosit 1165 remover and ultrasound. An image of a SAW device fabricated using this process is shown in figure 3.

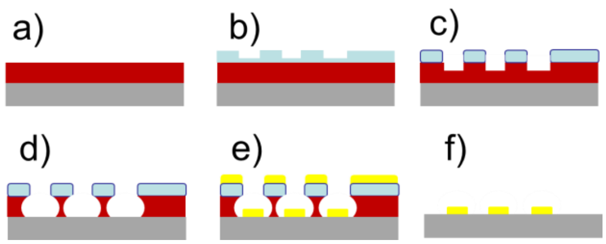

Figure 2. Fabrication process of SAW devices based on J-FIL patterning technique.

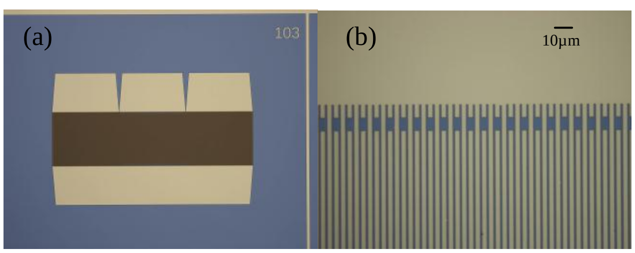

Figure 3. (a) SAW resonator fabricated using the J-FIL patterning technique and subsequent processing steps. (b) close-up view of the interdigital transducers (IDT) electrodes showing the high fidelity of the IDT electrodes.

3.1 IDT characterization

The width and height of the SAW IDTs were characterized by using AFM with an Nanosensors AR5T-NCHR ultra-sharp tip for five different devices on the wafer. An AFM profile is shown in figure 4 and a list of the measurements are seen in table 1. The measurements show that devices closer to the edge of the wafer have a larger line width, 2328 nm, than those near the center of the wafer, 2292 nm. This is probably due to a higher etch rate along the etch of the wafer during the dry etching in the development step[5], which causes large variations across the wafer of ±20 nm. The average IDT thickness and variation was measured to 97.2 nm and ±1.5 nm respectively, which is a modest value obtained through most point source e-beam evaporation deposition tools.

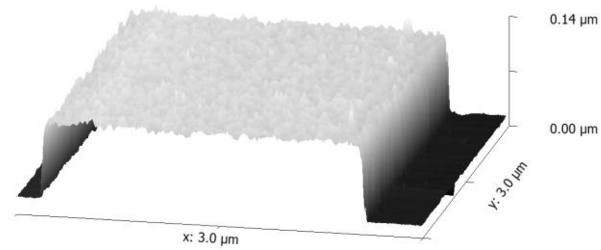

Figure 4. AFM image of the Al IDT structure used measure the IDT thickness and width.

Table 1. List of IDT width and thickness data measured through AFM characterization on five, design identical SAW devices.

Imprint #	Width [nm]	Thickness [nm]
03	2339	96.8
20	2334	98.8
23	2300	96.2
26	2333	95.8
43	2338	97.1
Average	**2329 ± 20**	**97.2 ± 1.5**

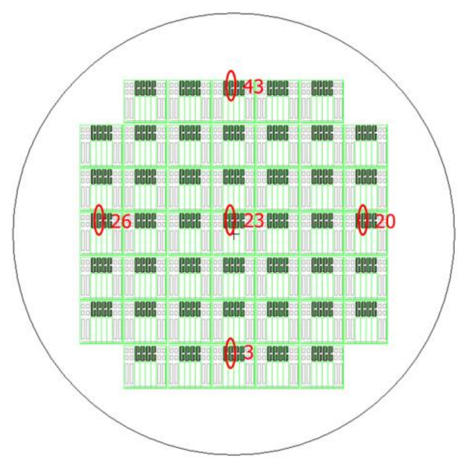

Figure 5. The wafer map showing the SAW devices measureed in table 1.

3.2 Electrical Characterization

The center frequency and Q-factor of the SAW devices were measured using a one-port scheme by using a network analyzer. The frequency responses of five design indendical SAW devices are shown in figure 6 and the corresponding center freqeuncy and Q-factor are listeed in table 2. The frequency dispersion was measured to be ±6.4 kHz, corresponding to 14 ppm. This is a factor 10 better than state-of-the-art quartz based SAW devices, which are fabricated using UV stepper lithography and directly demonstrates the potential the developed process to produce high fidelity and reproducible SAW devices.

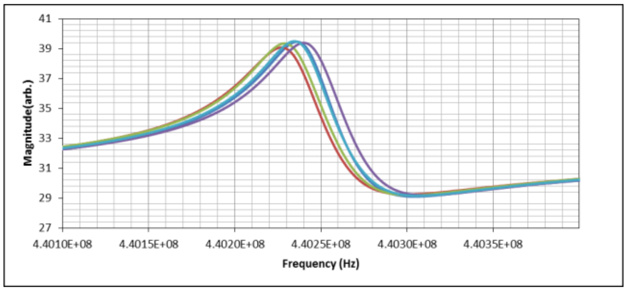

Figure 6. Frequency response of 5 (design identical) SAW devices on five different areas on a single 4" wafer.

Table 2. List of the center frequency and Q-factor for each of the five SAW measurements shown in figure 6.

Imprint #	Frequency [MHz]	Q Factor
03	440.2363	10000
20	440.2272	9100
23	440.2290	9500
26	440.2400	9600
43	440.2350	9900
Average	**440.23 ± 0.006**	**9620**

These results show that the high fidelity of the J-FIL patterning technique is enough to decrease the fabrication tolerances substantially. However, in order to reach the ambition goal of fabrication tolerancees below 10 ppm, optimization of the dry development as well as the metallization are imparative. Finite element analysis has shown that the variation in the IDT width needs to be less than 10 nm and thickness less than 1 nm respectively in order to meet the target 10 ppm frequency tolerance.

4. PROCESS OPTIMIZATION

4.1 IDT thickness optimization

The homogeneity of the metallization step has been improved by implementing a metal evaporator with a rotating substrate holder. The advantage of the rotating substrate holder is that the uniformity is excelent in the direction of the rotation and the uniformity in the perpendicular direction can be controlled by inserting a specially shaped shield between the target and substrate. An optimized shield can yield a very good uniformity. A custom made physical vapor deposition system (CyroFox Exlporer 700), which can perform evaporatioin as well as DC and RF sputtering on up to 12 wafers simultaneously on a rotating substrate holder. The CyroFox can also perform co-evaporation/sputtering from two targets, opening up the possibiltiy of deposition of alloys as well as single metals.

The thickness distribution for a single wafer can be seen in figure 7a and 4b. Figure 7a shows the distribution using the original uniformity shield and figure 7b shows the distribution when the shield has been optimized. The thickness variations across a single wafer (out of three) was reduced from ±2.4 nm to ±1.55 nm when using an optimzied uniformity shield during the evaporation deposition proces. Futher shield modifications are needed to reduce the thickness variations below ±0.5 nm, which is what is required to push the SAW fabrication tolerances below 10 ppm.

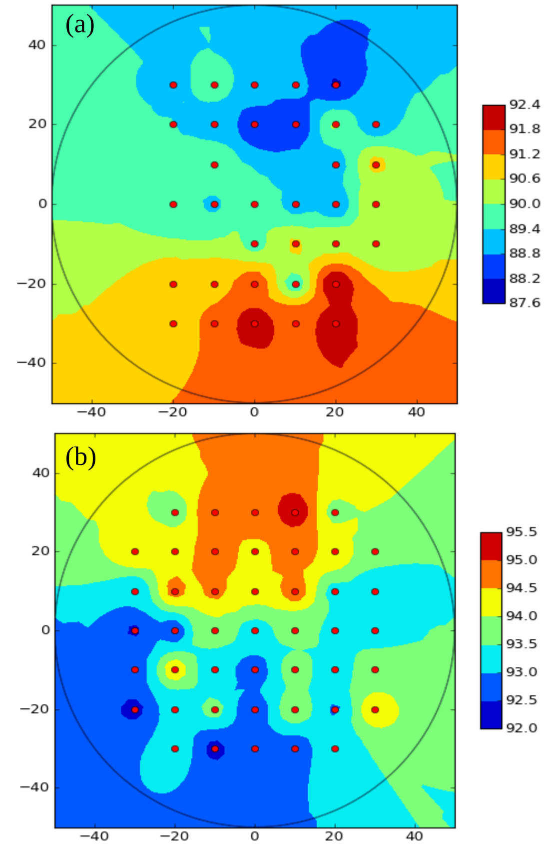

Figure 7. Plots of the metal thickness distribution over an entire wafer, where (a) the original metallization shield shows a modest variation of ±2.44 nm and (b) the optimized shield shows an improved variation of ±1.55 nm.

4.2 IDT width improvements

As seen in table 1, there was a large ±20 nm variation in the IDT width, which has been acrediced to the non-uniform etching during the dry based development procedure (c) and (d) in figure 2. In oder to improve this a new dry etching tool was implemented SPTS DRIE Pegasus, which allowed for better control of both the drying etching processes. Both process were optimized to reduce sidewall etch in the resist development step as it is determing step for the line width and less sidewall etch will reduce the importance variations in the etch rate. This was achieved by making the etch less chemical and more physcial. Through maticulus optimization, the new dry etching processes ultilized substrate cooling (-10^{0}C versus 20^{0}C), a higher ion bombardemnt, lower base pressure and higher Ar gas

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content, which resulted in a more physical anisotropic dry etch compared to the standard etchng processes. AFM analysis as again used to measure the IDT structures after lift-off and found that with the improved dry etching recipe the difference was below the AFM lateral resolution of approximately 5 nm as seen in table 3, thus there is no measurable difference with the improved dry etching technique.

In figure 8 an AFM image of a IDT section is shown using the optimized development process. Even thoguh the width tolerance is below 1%, a non ideal IDT profile has been observed (batman ears), which suggest that the dry etching of the planarization layer is highly anisotropic. The high anisotropic etch together with the rotating substrate metal deposition could have caused the metal deposition on the sidewalls. This can be remidied by decreasing the anisotopic nature or by adding a short pure O_2 plasma etch subsequent to the planarization etch, in order to slightly underetch the imprint resist.

Table 3. AFM data of the width of IDT structrues using the improved dry etching based development

	Width [nm]	3σ [nm]
Center	1228	± 6
Edge	1229	± 8
Total	1229	± 5

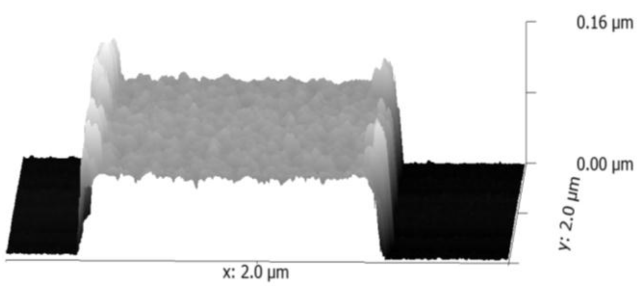

Figure 8. AFM scan of a 1.2µm wide electrode after using the optimized development process. The width tolerance is reduced to under 1%, however the profile is not ideal (batman ears), which could have an unwanted effect on the frequency dispersion.

5. CONCLUSIONS

A nanoimprint based process for the production of surface acoustic wave (SAW) devices has been presented. Initial results show that the fabrication tolerances for a single wafer are below 20 ppm, which is a factor 10 better than commercial quartz based SAW devices available on the market. Process optimization has been performed in order to further reduce these fabricatin tolerances, through maticulous optimization of the dry etching development steps subsequent to the Jet and Flash Imprint Lithography (J-FIL) and optimization of the the metallization homogeniety though use of a rotating wafer holder, capable of batch processing with a metal thickness tolerance less than ±1.55 nm. These results are currently being adapted into a pilot production of SAW devices, which will demonstrate fabrication tolerances below 10 ppm, which will lead to cost effective nano-manufacturing of low noise communication devices and calibration free SAW sensors.

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