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HAPTIC INTERFACE BASED ON AN INNOVATIVE “PIEZO-IN-FLEX” PIEZOELECTRIC PATCH TECHNOLOGY

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ABSTRACT

The tremendous development of tactile interface in many customers applications, such as smartphone, leads industrials to study “haptic interfaces” which allow the user to interact with its environment by the sense of touch. Piezoelectric actuators are commonly used to actuate such interfaces. In this paper, we present a new and innovative technology to integrate collectively commercial piezoceramics into flexible piezoelectric patches able to be integrated on any surface. The “piezo-in-flex” technology include the control of the piezoelectric actuator thickness through a grinding step. Piezoelectric actuator in the 10 – 100 μm range can be obtained in order to develop high performance and low consumption haptic interfaces. We glue the piezoelectric flexible patch on a $4 \times 3 \text{ cm}^2$ glass plate to obtain a plug and play haptic interface. A displacement amplitude of 1.15 μm was measured on a Lamb mode at 58.49 kHz, using only 25 V. A haptic effect was felt by the finger when we modulate at 50 Hz the actuation signal, proving the potential of our “piezo-in-flex” haptic interface.

KEYWORDS

Haptic interface, piezo-in-flex, piezoelectric, patch, flexible, conformable.

INTRODUCTION

Many customer applications target high performance, low consumption haptic interfaces. Among the different haptic solutions, squeeze-film effect is one of the most promising ones. It provides high granularity level of haptic sensation, playing with the variable friction between a finger and a resonant plate, when the plate displacement amplitude reaches about 1 μm in a flexural anti-symmetric Lamb mode [1, 2, 3, 4]. To promote the desired mode, we use piezoelectric actuators and bimorph effect.

However, to reduce the power consumption, linked to the piezoelectric material thickness, today, there is a need for “thick” films, in between thin-films actuators (thickness less than 10 μm , using sol-gel, spin coating or pulverization technics) [5, 6, 7] and bulk piezoceramics (thickness higher than 100 μm and requiring one by one integration) [8, 9]. Thin-film actuators induce high capacitance values and thus high power consumption, whereas bulk piezoceramics induce high actuation voltage linked to the high thickness.

In this paper, we present a new and innovative technology to integrate collectively commercial piezoceramics with a controlled thickness, into flexible piezoelectric patches able to be integrated on any surface, in order to provide efficient haptic interfaces. The controlled thickness, in the 10 – 100 μm range, allow to

obtain high performance and low consumption haptic interfaces.

COMSOL Multiphysics® was used to design the $4 \times 3 \text{ cm}^2$ haptic interface. Our “piezo-in-flex” technology leads to haptic interface with the desired resonant mode at 59.4 kHz and a displacement amplitude of 1.15 μm under 25 V ac/peak-to-peak. A haptic feedback effect was felt on the plate by using an actuation signal modulated at 50 Hz in amplitude. It proves the possibility to obtain the haptic feedback effect through our innovative “piezo-in-flex” technology.

DESIGN AND TECHNOLOGY

COMSOL Multiphysics® was used to design the $4 \times 3 \text{ cm}^2$ haptic interface. Our model consists in an unclamped 500 μm thick plate made of glass with 90 μm thick PZT actuators. Through modal simulation, a Lamb mode at 59.6 kHz was selected (Figure 1).

Then relative harmonic simulations were performed to determine the best positioning of the piezoelectric actuators on the glass plate. In particular, two actuator columns, consisting each into two serial $13 \times 3 \text{ mm}^2$ actuators, localized respectively at 1900 μm of each edge of the plate, as shown in Figure 1, leads to the highest displacement amplitude. We positioned the piezoelectric actuators on maximum displacement amplitude areas in order to maximize their efficiency. Table 1 resumes the main dimensions of the haptic plate.

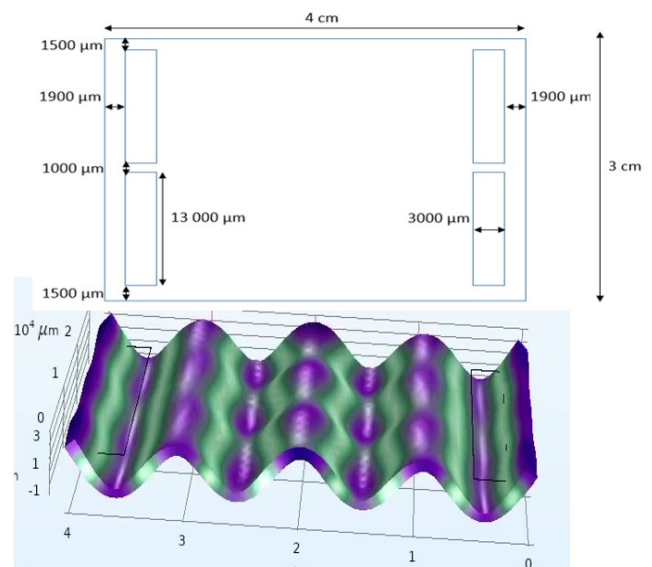


Figure 1: Device layout with main dimensions and modal shape of the antisymmetric Lamb mode at 59.6 kHz, simulated on a $4 \times 3 \text{ cm}^2$ glass plate.

Table 1: Main dimensions of the haptic plate.

Characteristic	Size	Unit
Plate size L×w	4×3	cm
Plate thickness h	500	μm
Individual actuator La×wa	13 000×3 000	μm
Actuator number	2×2	-
Distance between actuator	1 000	μm
Distance actuator – width edge of the plate	1 900	μm
Distance actuator – length edge of the plate	1 500	μm

We developed an innovative “piezo-in-flex” process to integrate collectively commercial piezoceramic actuators in flexible patches.

We laminated an 80 μm-thick SINR dry film on a standard 8-inch silicon wafer [10]. A 200 nm-thick gold layer was deposited by PVD and patterned on top of the dry film to form the bottom electrical lines. After the serigraphy of glue, we positioned commercial AP850 piezoceramics using a pick & place tool (DATACON 2200 Evo advanced). Then, an underfill polymer (Namics G8345-146) was deposited around the actuators using a Nordson Asymtec S920 tool.

The piezoceramics were grinded down to the desired optimal actuator thickness, namely 90 μm. Figure 2 gives a photography of a wafer after underfill deposition and a SEM cross section of the 90 μm-thick piezoceramic after grinding. Then, we deposited gold as top electrode using evaporation technic and a shadow mask.

Views of the main steps of the fabrication process are illustrated in Figure 3.

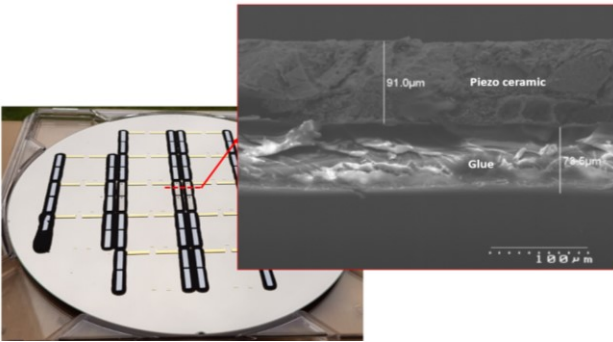


Figure 2: SEM cross section of the 90 μm residual thickness of the piezoceramic after grinding.

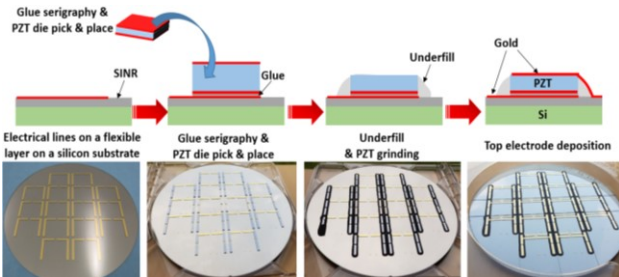


Figure 3: Schematic cross-section and picture of an 8-inch wafer showing the main steps of the piezoelectric patch process.

Finally, piezoelectric patches are peeled from the silicon substrate, and a flexible electrical connector is bonded on the patch, for a plug and play actuator solution. Figure 4 gives a photography of a silicon wafer with the SINR film peeled and of a piezoelectric patch with four grinded piezoceramic actuators and its gold electrical lines, and flexible connector bonded on it.

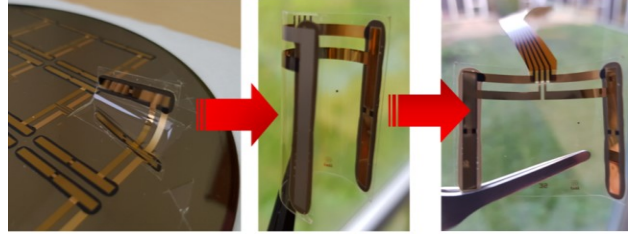


Figure 4: Photography of a silicon wafer with the SINR film peeled and of a piezoelectric patch with four grinded piezoceramic actuators and its gold electrical lines, and flexible connector bonded on it.

In the present work, we glued the flexible patch on a 4×3 cm² glass plate with a thickness of 500 μm (EAGLE XG[®]) using a UV glue EPOTEK OG133-8. The haptic device using the “piezo-in-flex” piezoelectric patch can be seen in Figure 5.



Figure 5: Photography of the 4×3 cm² glass plate with the “piezo-in-flex” piezoelectric patch.

EXPERIMENTAL RESULTS

Optical measurements of piezo-actuated vibrating plates were performed using laser vibrometry. The apparatus uses interferometry to measure the velocity of vibrating points of the plate surface. We applied a white noise excitation to the top electrode of the 4×3 cm² plate simulated at 59.6 kHz. Using a POLYTEC MSA400 tool (Figure 6), we measured the desired resonant mode at 59.4 kHz.

Figure 7 shows the frequency spectrum that enabled us to identify the selected mode. At this resonant frequency, several measurements have been necessary to build the plate’s whole picture as shown in Figure 7. The mode shape is in good agreement with the selected one, reported in Figure 1. The agreement between measurement and simulation is very good. Indeed a discrepancy less than 1% is noticed.



Figure 6: Laser vibrometer POLYTEC MSA400 tool with the haptic plate.

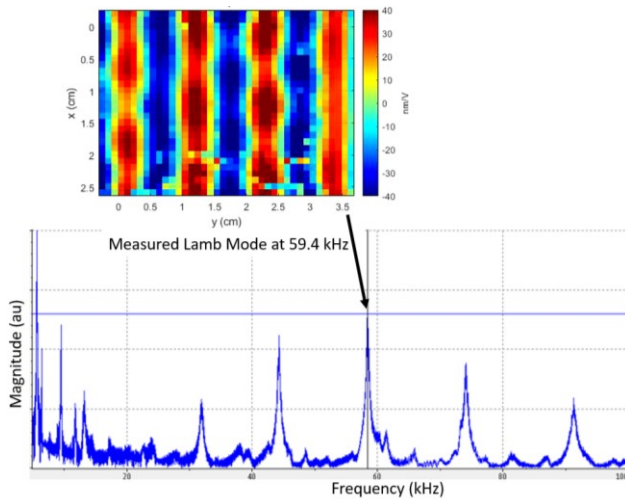


Figure 7: Laser vibrometer measurement, using a POLYTEC MSA400, of the displacement amplitude of the 4×3 cm² plate (under white noise excitation) versus the frequency.

At the resonant frequency, the substrate displacement amplitude of $1.15 \mu\text{m}$ under 25 V ac /peak-to-peak was measured. Figure 8 gives the substrate displacement amplitude regarding the actuation voltage. As expected for a piezoelectric actuator, a linear dependence of the displacement amplitude function of the actuation voltage is observed. In this figure, we also compared the substrate displacement amplitude of the “piezo-in-flex” plate with that obtained on a plate with a classical “non grinded” ceramic ($300 \mu\text{m}$ thick) and with that obtained on a plate with a thin-film AlN actuator ($2 \mu\text{m}$ thick).

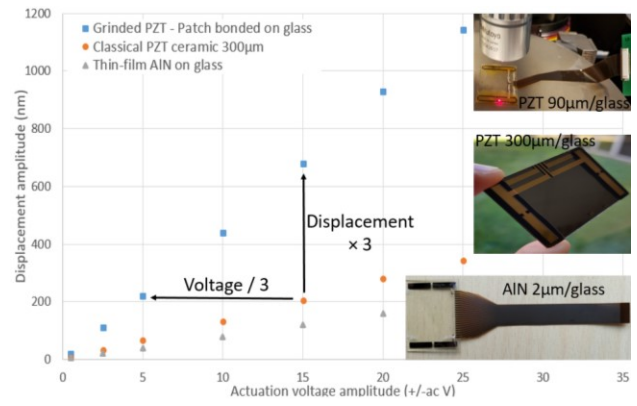


Figure 8: Laser vibrometer measurement of the displacement amplitude of the 4×3 cm² glass plate versus the actuation voltage – Comparison between grinded PZT and classical ceramic and thin-film AlN actuators ($2 \mu\text{m}$).

The “piezo-in-flex” technology with the grinding step allows to higher displacement amplitudes (alternatively lower actuation voltages) compared to other actuator technology such as non-grinded commercial AP850 piezoceramic or thin-film AlN actuator integrated on glass using the same plate design (Figure 8). Table 2 resumes this study. One can note that the “piezo-in-flex” technology allows to obtain higher displacement amplitude for a given actuation voltage compared to classical non-grinded ceramic and thin-film piezoelectric actuators. Moreover, we can obtain a higher energy efficiency, defined as being the square of the displacement amplitude divided by the capacitance. It proves the potentiality of the “piezo-in-flex” technology.

A haptic feedback effect was felt on the plate by using an actuation signal modulated at 50 Hz in amplitude. It proves the possibility to obtain the haptic feedback effect through our innovative “piezo-in-flex” technology; that fill the technological gap between thin-film actuators and piezoceramics, in order to develop high performance, low consumption haptic interfaces.

Table 2: Performance of the grinded actuators of the “piezo-in-flex” technology compared to performance of commercial piezoceramic and thin-film AlN actuators on 4×3 cm² haptic interfaces.

Actuator	AlN ($2 \mu\text{m}$)	Commercial AP850 PZT ceramic ($300 \mu\text{m}$)	Piezo-in-flex Grinded PZT ceramic ($90 \mu\text{m}$)
Displacement amplitude A, under 20 Vac (nm)	160	300	1 000
Capacitance C (nF)	5.5	7	23
Energy efficiency A^2/C (nm ² /nF)	4 654	12 857	43 478

CONCLUSION

In this paper, we presented the design and the realization of a haptic interface based on an innovative “piezo-in-flex” process to integrate collectively commercial piezoceramic actuators in flexible patches. We measured the desired resonant frequency at 59.4 kHz, in good agreement with the simulated one (59.6 kHz). Indeed a discrepancy less than 1% is noticed. At the resonant frequency, a displacement amplitude of 1.15 μm under 25 V ac/peak-to-peak was measured for the 4 \times 3 cm² haptic plate. This displacement amplitude is compatible with a haptic effect. The “piezo-in-flex” technology with the grinding step allows to higher displacement amplitudes compared to other actuator technology such as non-grinded commercial piezoceramic or thin-film actuator integrated on glass using the same plate design. A haptic feedback effect was felt on the plate by using an actuation signal modulated at 50 Hz in amplitude. It proves the possibility to obtain the haptic feedback effect through our innovative “piezo-in-flex” technology; that fill the technological gap between thin-film actuators and piezoceramics, in order to develop high performance, low consumption haptic interfaces.

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