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4-inch transparent plates based on thin-film AlN actuators for haptic applications

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ABSTRACT

Numerous applications require tactile interfaces today. In particular, many customers' applications such as automotive, Smartphone, tablet PC or touch pad can be concerned by high performances, low voltage haptic interfaces which allow the user to interact with its environment by the sense of touch. This technology is already used but with limitations such as high power consumption and limited feedback effect because today a simple vibration is commonly obtained. We chose to work on the squeeze-film effect. It consists in changing the friction between the finger and a plate resonator. It provides high granularity level of haptic sensation. This paper deals with the design, realization and characterization of high performances actuators in order to promote the squeeze-film effect on a 4-inch transparent plate (diagonal of the plate). Using Finite Element Method (FEM) models, we select the best design, able to generate the highest plate displacement amplitude as possible. We built demonstrators using a generic technology based on thin-film Aluminum Nitride (AlN) actuators on glass substrate. Electromechanical characterizations prove that it is possible to obtain the focused substrate vibration amplitude using only 35 V in amplitude. The integration of the thin-film actuator plate in a haptic demonstrator is now ongoing.

1. Introduction

Recent demand in new tactile interfaces in many customers' application such as Smartphones or tablet PCs, has focused research efforts towards developing high performances transparency haptic interfaces. Among the different haptic solutions [1–4], 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 (PDA) reaches about 1 µm in a flexural anti-symmetric Lamb mode [5–8]. To promote the desired mode, we use piezoelectric actuators and bimorph effect. We developed Finite Element Method (FEM) models and proved the concept using thin-film PZT actuators deposited on silicon substrate [9–10]. Nevertheless, to address transparency, low temperature process was used, to deposit AlN actuators directly on transparent glass substrate [11].

This paper reports first on the design of thin-film AlN actuated haptic plates. Using our FEM models, we proposed an actuator design able to promote the required PDA to a 4-inch transparent plate (diagonal of the transparent area of the plate) [12]. Then the technological stack used to build demonstrators is presented. Finally, electromechanical characterizations prove that we meet the micrometric substrate displacement amplitude specification for only 35 V. The haptic plate will be integrated in a thin-film haptic demonstrator, in order to obtain complex haptic effect in a close future.

2. Design

We designed high performances thin-film AlN actuated haptic plates using FEM approach and CoventorWare® tool. Our model consists in the study of unclamped 700 µm thick plates made of glass with 2 µm thick AlN actuators. Thus, as it will be explained in Section 3, no clamping condition is applied to the glass plate. Previous work on PZT actuated silicon plates validates this hypothesis [13]. We neglected top and bottom electrodes on both sides of the AlN layer due to their low impact on the PDA. Indeed, as it will be detailed later (Section 3), top and bottom electrode thicknesses (220 nm) are negligible compared to the glass substrate thickness

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Table 1.
Material properties.

Material	Young's modulus (GPa)	Poisson's ratio	Density (g/cm^3)	$e_{31,f}$ (C/m^2)
AlN	300	0.3	3.27	-1.1
Glass	73.6	0.23	2.38	-

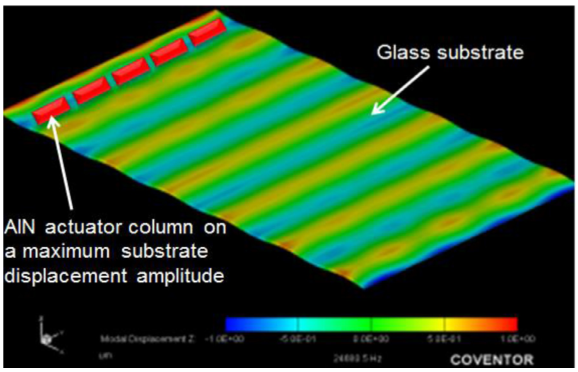

Fig. 1. . Modal simulation on a 110 × 65 mm² glass plate for actuator column positioning – View of the selected mode, f = 24.68 kHz.

(700 µm). Thus we suppose that their contribution to the system stiffness is negligible.

The material properties used in the FEM model are given in Table 1. The AlN mechanical material properties are coming from picosecond ultrasonics measurement (details on this measurement technique can be found in [14–15]), whereas the Glass material properties are coming from the data sheet of this commercial material (EAGLE XG®). The piezoelectric coefficient $e_{31,f}$ is extracted from electromechanical measurements performed on an AlN-actuated cantilever, in particular using an AixACCT tool [16].

The simulation procedure consists of a modal simulation to select the adequate mode to promote the squeeze-film effect, and then of harmonic simulations to design actuators leading to the highest substrate displacement amplitude.

First, modal simulation was performed on a 110 × 65 mm² plate to determine the frequency of the flexural anti-symmetric Lamb modes known to promote the squeeze-film effect [5–8]. Among these modes we select a mode presenting a frequency beyond audible frequencies. We chose to work with a mode at 24.68 kHz as shown in Fig. 1.

We accurately positioned an actuator column (AC1) by taking the deformed shape of the selected mode into account, and matching the actuators' position with the maximum PDA. The actuator column consists in 5 individual actuators (each actuator length, L_{AC} = 12,208 µm in the y direction). Fig. 2 gives a schematic diagram of this first FEM model.

Then, harmonic simulations were performed in order to define the optimum actuator column width and localization. We applied 60 V to the top electrodes of the AlN actuators, whereas 0 V is applied to the bottom ones. We introduce a damping parameter of 7.10^{-8} to predict the absolute PDA of our plate under 60 V. This damping parameter is coming from the comparison between PDAs measurement and post simulation on 60 × 40 and 40 × 30 mm² haptic plates [9]. This previous calibration step of our FEM model led us to estimate the adequate damping parameter for the 110 × 65 mm² plate study.

An actuator width W_{AC} = 7175 µm, located at B = 6110 µm from the end of the plate exhibit the best performances. The actuator width study can be observed in Fig. 3 and the optimal position of the actuator is determined in Fig. 4.

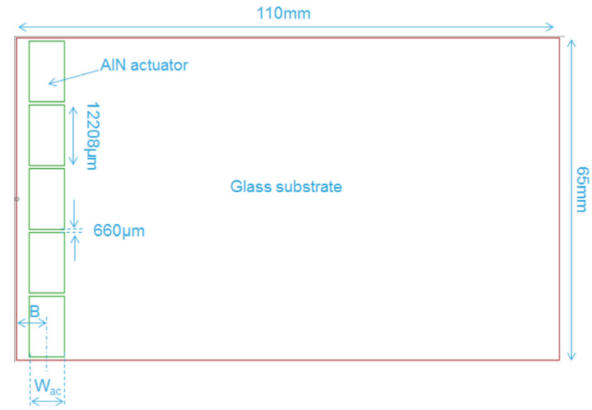

Fig. 2. . Schematic diagram of the FEM model.

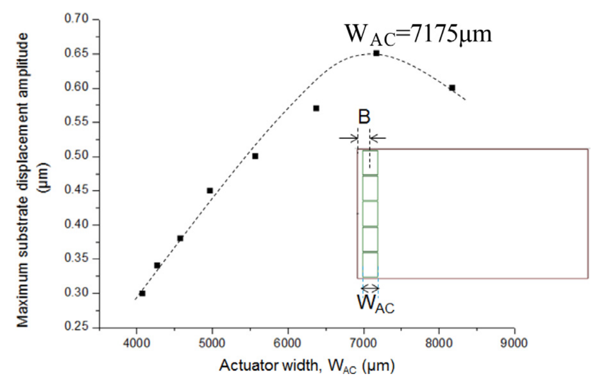

Fig. 3. Optimum actuator width for a 110 × 65 mm² glass plate determined using harmonic simulations (60 V and B = 6110 µm).

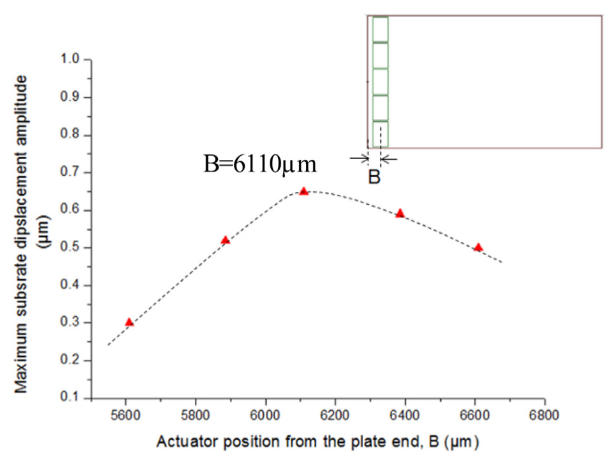

Fig. 4. Optimum actuator localization for a 110 × 65 mm² glass plate determined using harmonic simulations (60 V and WAC = 7175 µm).

A second actuator column at the opposite plate end (*AC2*), as well as actuators localized along the plate length ends, were also positioned (Actuators along the plate length: *AL* actuators) taking into account the vibration mode shown in Fig. 1. The complete implementation can be observed in Fig. 5 and the main dimensions are given in Table 2.

As expected, the 110 × 65 mm² plate presents a transparent area, between the actuators, of about 4-inch in diagonal (9.06 × 4.9 mm²).

One can note that several actuator configurations can be used: AC1 and/or AC2, AC1-in-phase AL actuators and/or AC1-out-of-phase AL actuators, or actuators.

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