SIMULATION AND FABRICATION OF PIEZOELECTRIC MEMS RESONATORS

Jaroslav Klempa

Bachelor Degree Programme (3), FEEC BUT

E-mail: xklemp00@stud.feec.vutbr.cz

Supervised by: Imrich Gablech

E-mail: imrich.gablech@ceitec.vutbr.cz

Abstract: This paper presents FEM analyses and fabrication of piezoelectric MEMS resonators. Modal and harmonic analyses were made using Ansys® Workbench. These simulations showed the influence of resonators geometry on their out-of-plane displacement and corresponding resonant frequencies. Piezoelectric resonators were fabricated by standard microfabrication processing compatible with complementary metal-oxide-semiconductor (CMOS) technology.

Keywords: Piezoelectric resonator, MEMS, thin films, FEM analyses

1 INTRODUCTION

Development of microelectromechanical systems (MEMS) started in late 60s. Since then huge demand on miniaturization, improved stability and efficiency was requested with every electronic device. MEMS can offer these things by incorporating mechanical moving parts to electronic circuits. Most of the current development is focused on the manufacture of reliable sensors. One of the most successful examples are pressure sensors and infrared cameras used in almost every new car and military applications, respectively [1,2]. MEMS resonators are also widely used in many industrial applications such as inertial sensors and gyroscopes. The change in the resonant frequency can be also used for detection of adsorbed molecules, which can be used for example to weigh molecules or for detecting certain substances [3].

2 EXPERIMENTAL

The piezoelectric resonator was realized as one clamped cantilever beam (Fig. 1a). In the principle, the beam is actuated at resonant frequency utilizing piezoelectric properties of AlN between two electrodes. Each fabricated resonator consists of five layers deposited on 4-inch Si wafer.

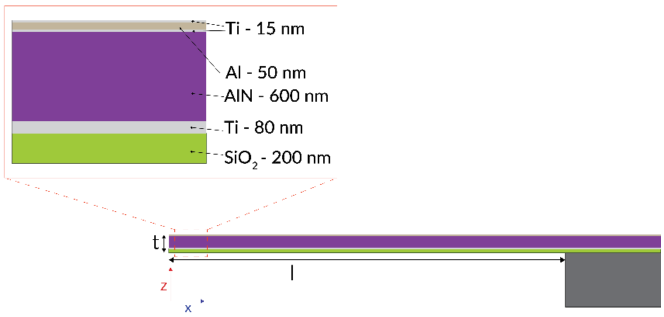

Figure 1: Structure of cantilever beam.

The bottom low stress 200 nm thick SiO_2 prepared by plasma-enhanced chemical vapour deposition (PECVD) is used as a structural layer. Next layers were then prepared using physical vapour deposition (PVD) by a Kaufman ion-beam source to achieve high quality and controlled parameters of deposited thin films. The bottom 80 nm thick Ti thin film serves as an electrode and a seed layer for consequent AlN deposition. The AlN with thickness of 600 nm grown on Ti has better parameters due to their similar lattice parameters and crystal structure. The top electrode consists of 15 nm thick Ti adhesion layer and 50 nm Al layer.

2.1 FEM ANALYSES

Modal and harmonic analyses were carried out using Ansys Workbench 17.2. The piezoelectric resonators as cantilever beams were simulated with different dimensions. We determined how different dimensions influence the resonant frequency and displacement. Fig. 2 shows that the length (*l*) of cantilever has exponential decay dependence on its resonant frequency, while the width (*w*) change is marginal. Increasing thickness of AlN also increases resonant frequency.

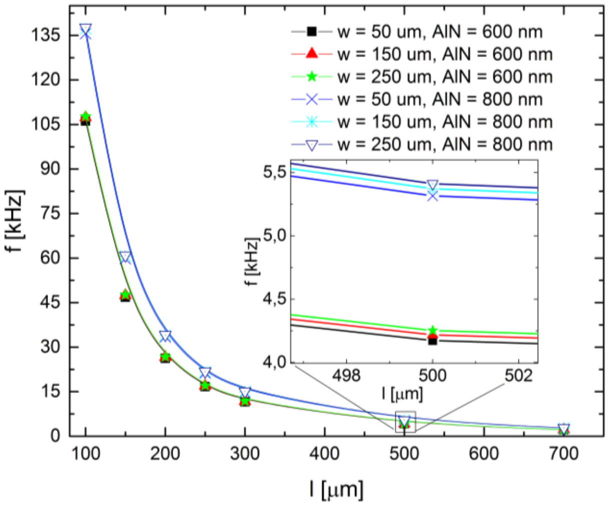

Figure 2: Simulated resonant frequencies for different lengths, widths and thicknesses of cantilever beams.

2.2 FARICATION

Fabrication process flow is outlined in the Fig. 3. Process starts with semiconductor standard Si wafer on which all thin layers were deposited as described previously (Fig. 3a).

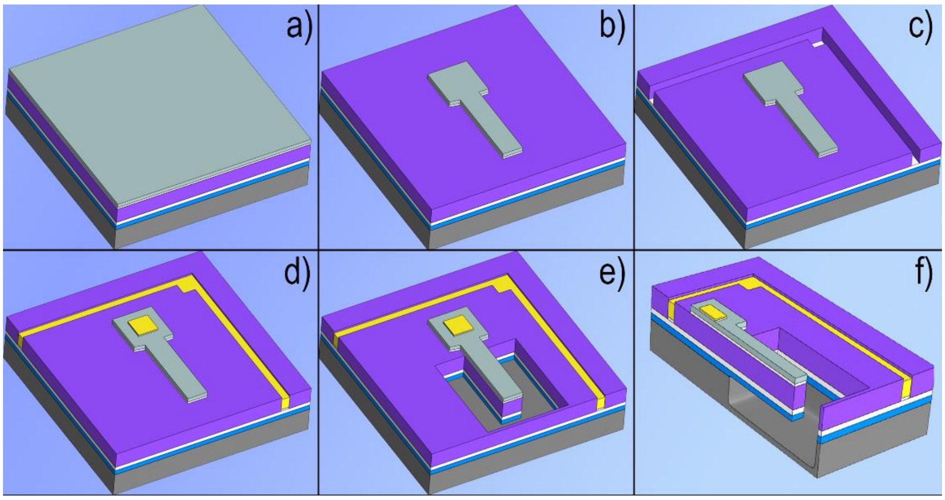

Figure 3: Schematic of fabrication process (not to scale): a) all deposited layers on Si wafer, b) shaped top electrode, c) exposed bottom electrode, d) lift-off deposition of gold for wire bonding, e) removal of excess material surrounding the resonator, f) section view of released cantilever with XeF_2.

The first step in the beam fabrication is the shaping of the top electrode. This consists of deposition of negative photoresist using spin-coating technique, followed by soft baking on hot-plate. Exposure was carried out by direct write lithography. After the exposure, the negative photoresist needs to be crosslink baked. The follow up consists of development in the solution of TMAH and water which removes the unexposed parts of the photoresist and rinse in water to get rid of any traces of the developer. Ion milling machine equipped with spectrometer for precise end-point detection of sputtered elements is then used to remove the unprotected areas of the top Al layer. The Ti thin film was then etched by reactive ion etching using SF6/O2 plasma discharge. As shown in the Fig. 3b, the top electrode is created. The second step starts with lithography using positive photoresist and is followed up by ion milling which then provides access to common ground Ti electrode (Fig. 3c). The Ti adhesion layer and Au layer are then deposited using lift-off technique to make contacts for wire bonding (Fig. 3d). The third step involves lithography around the main beam structure to remove the excess material using ion milling through all layers and stops at the Si substrate (Fig. 2e). Whole structure is then released using XeF_2 isotropic etching (Fig. 2f) in the last step.

SEM photographs of fabricated resonators are shown in Fig 4. The bending is caused by residual compressive stress in PECVD SiO_2. Nevertheless, the influence of a such bending is neligible in terms of electro-mechanical properties of piezoelectric resonator.

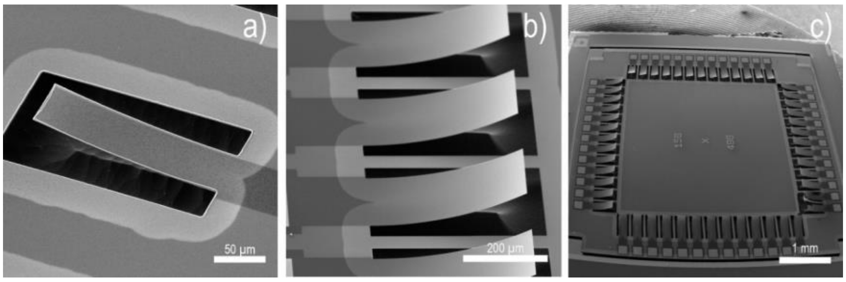

Figure 4: SEM photographs of manufactured resonators: a) single cantilever with etched groove, b) detail on cantilever array, c) cantilever array.

3 CONCLUSIONS

This work presented simulation and fabrication of piezoelectric MEMS resonators. FEM analysis results show how resonator dimensions affect the resonant frequency. These results can be used to tailor devices with desired resonant frequencies for specific application. Fabrication process is fully compatible with CMOS technology thus these structures can be integrated into chip with electrical circuits. All materials are also biocompatible which opens new possibilities for applications such as low energy consumption cochlear implants, infrared bolometers, very precise weight measurements and detections of living cells or gaseous substances.

ACKNOWLEDMENT

Part of the work was carried out with the support of CEITEC Nano Research Infrastructure (MEYS CR, 2016–2019).

REFERENCES

[1] MALUF, N. a WILLIAMS, K. Introduction to Microelectromechanical Systems Engineering. Artech House, 2004. ISBN 9781580535915.

[2] BRENDLEY, K. W. a STEEB, R. Military applications of microelectromechanical systems. DTIC Document.

[3] BRAND, O. et al. Resonant MEMS: fundamentals, implementation and applicatiom. Weinheim: Wiley-VCH Verlag GmbH & Co. KGaA, 2015. ISBN 9783527335459.