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A Piezo-MEMS Device for Fatigue Testing of Thin Metal Layers

micromachines
MDPI

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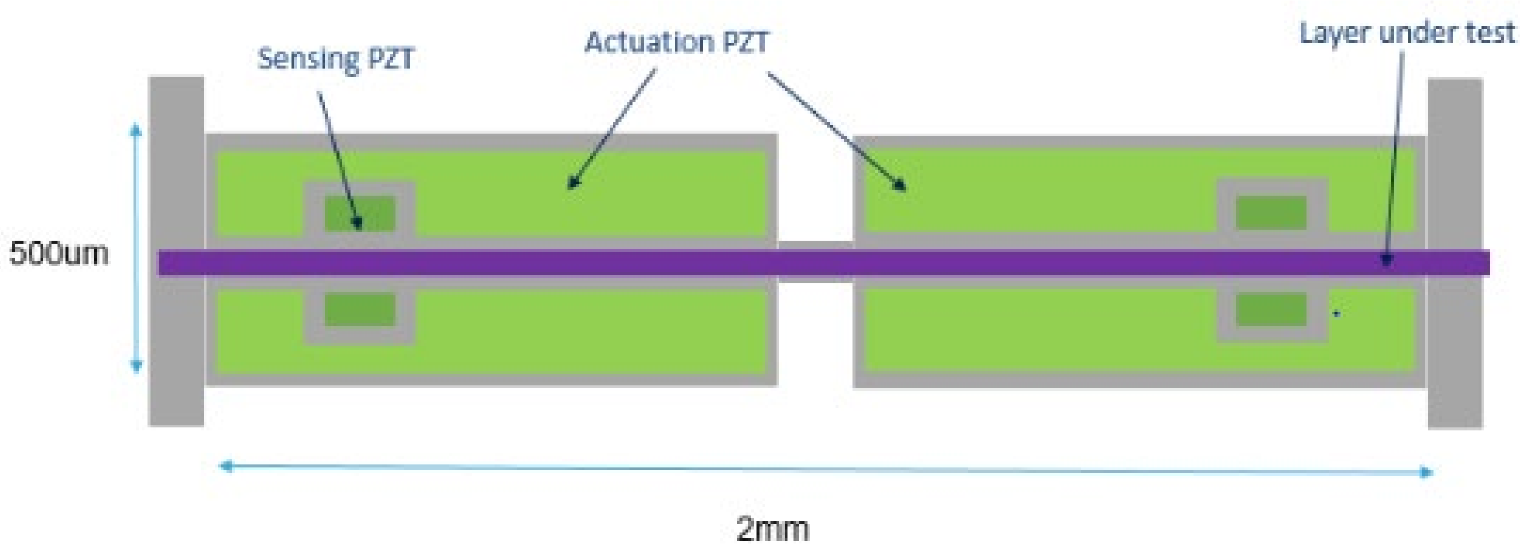
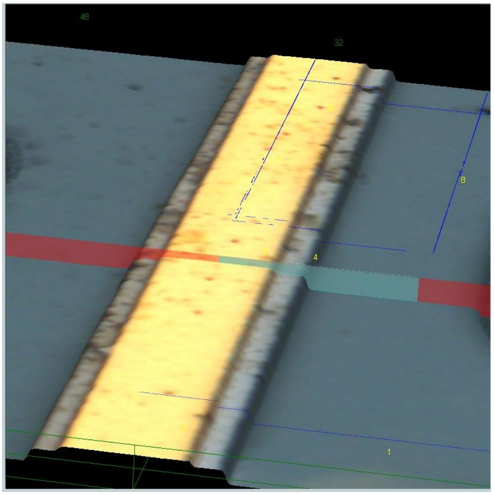
A Piezo-MEMS Device for Fatigue Testing of Thin Metal Layers





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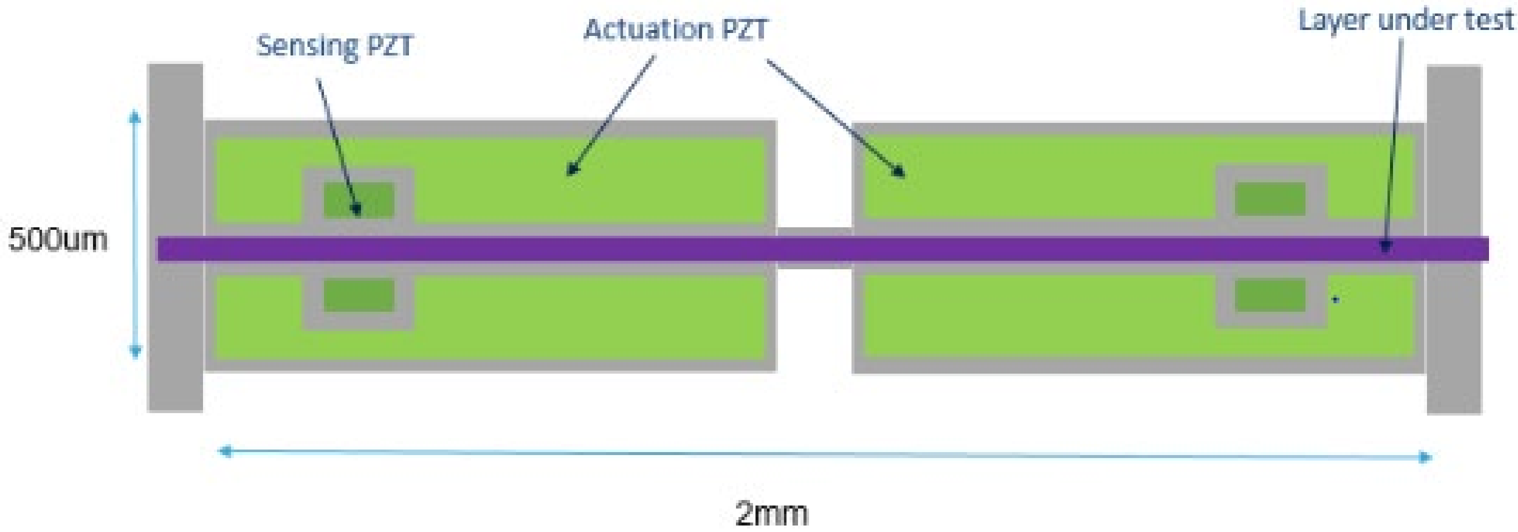
Abstract: Several micro devices, such as micro-mirrors, are subjected to working conditions featuring alternating loadings that can possibly induce fatigue in the thin metal layers, which represent critical structural parts.
The quantification of the degradation of the material properties under fatigue loading is a time consuming task, and the effects of environmental conditions (e.g. humidity) and load characteristics (e.g. frequency, stress ratio) must be properly accounted for.
In this work, we propose and assess the efficiency of an on-chip test device based on piezoelectric actuators, able to generate a time-varying (sinusoidal) strain in the mentioned thin metal layers and lead to fatigue. The aim of the research activity is the characterization of the stress/strain-induced degradation process of a thin layer located on the top of a lead zirconate titanate (PZT) actuation system. The characterization has been carried out through measurements of resistivity and roughness, respectively carried out via an ohmmeter and a confocal microscope. The proposed testing device has shown capability to qualitatively highlight the degradation of the metal layers.

Keywords: piezo-MEMS; fatigue; layered thin films

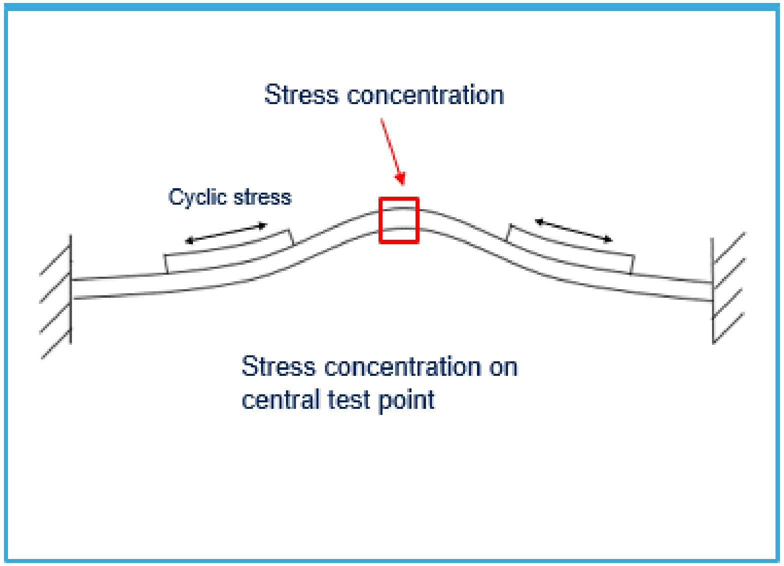
Schematic of the device and its components



top view

The piezoelectric actuators excite the out-of-plane deflection of the plates; the layered thin films (in violet above) connect as a bridge the two halves, to concentrate there the stress.

By tuning the input voltage, alternating-in-sign stresses are applied.



lateral view

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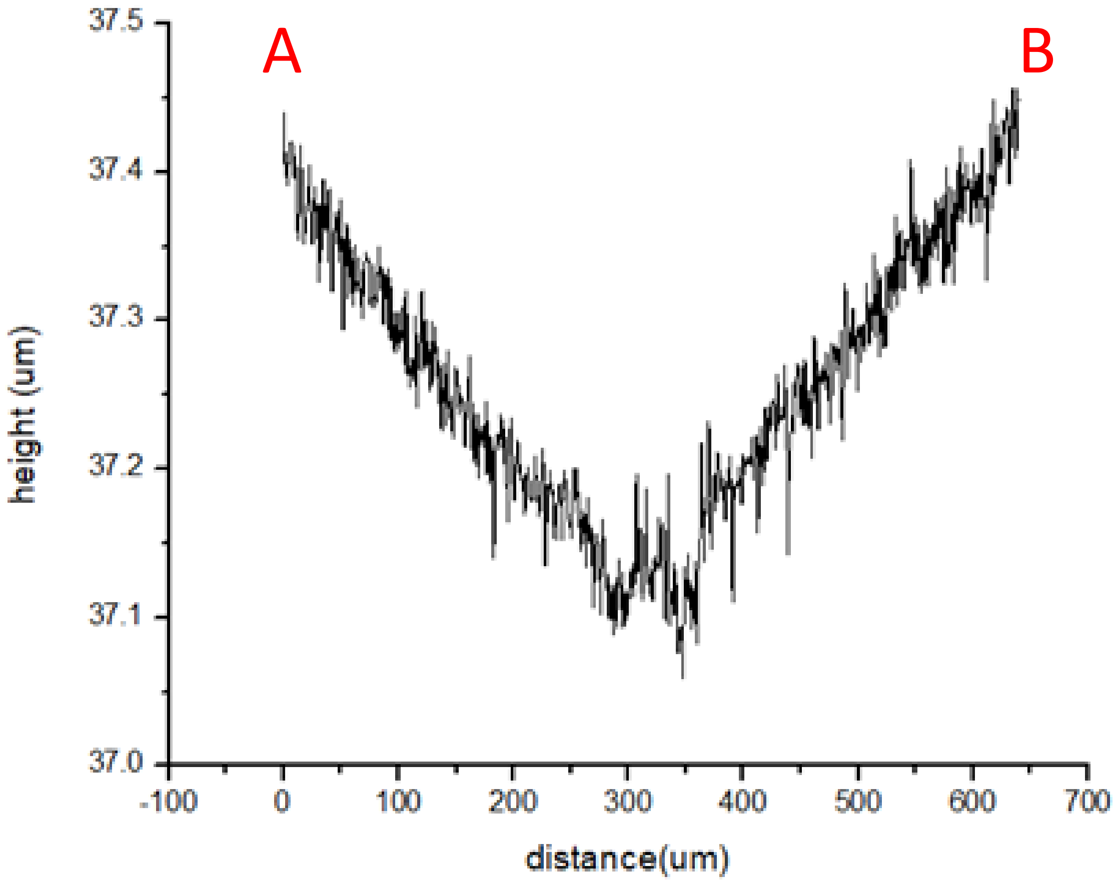
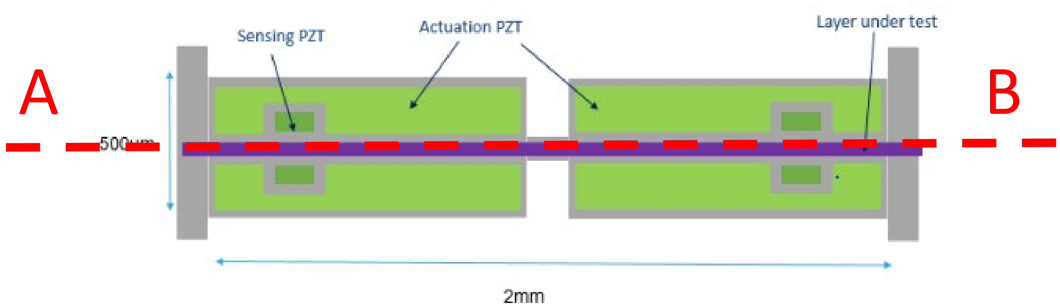
Initial configuration

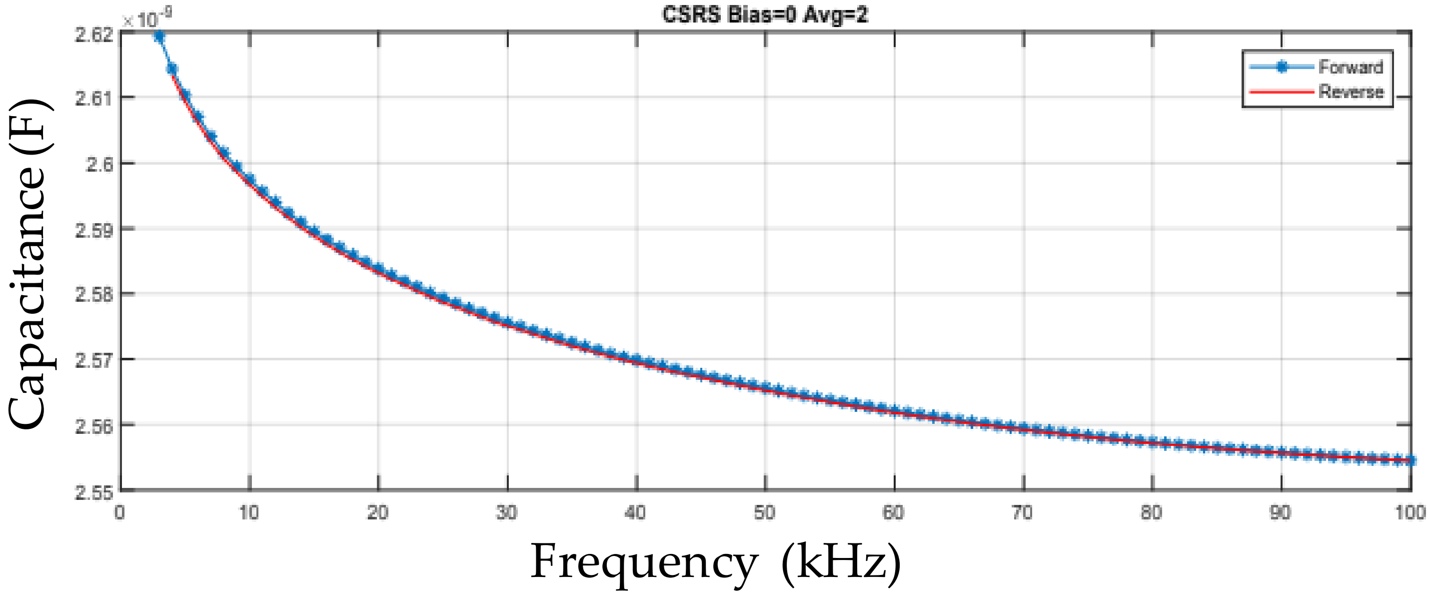




Initially, the device is bent downwards because of residual stresses caused by the poling and the deposition process.

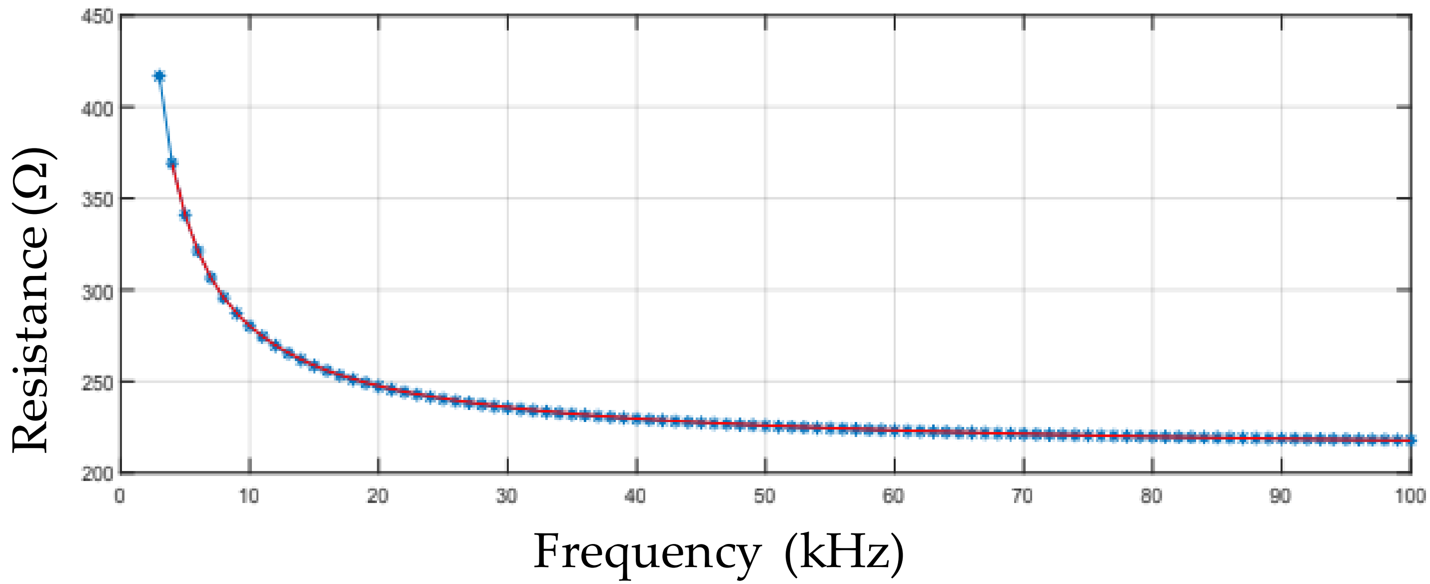
The maximum out-of-plane displacement is at the center, where the bridge connection is placed between the two plates.

Initial characterization



The capacitance shows a decrease as the frequency is increased.

The alignment of the domains within the system is a time-consuming process.



The same behavior is shown by the resistance measured from the device

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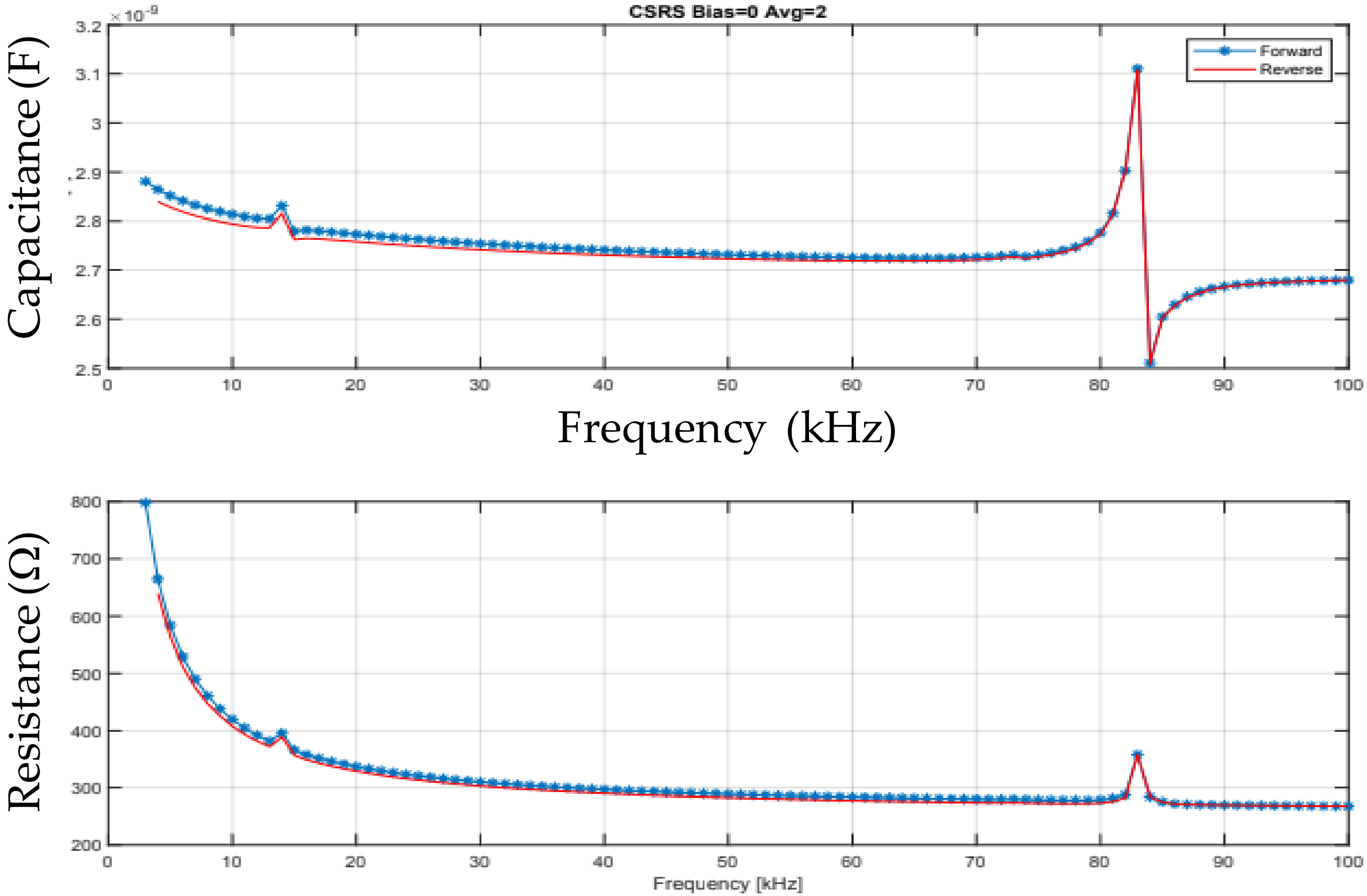
Characterization after 1-hour cycling



After cycling for an hour with an input of 60Vpp (0-60V) and a frequency of 20 kHz, we have :

- a plateau in the capacitance;
- two peaks located at the torsional and first bending mode.

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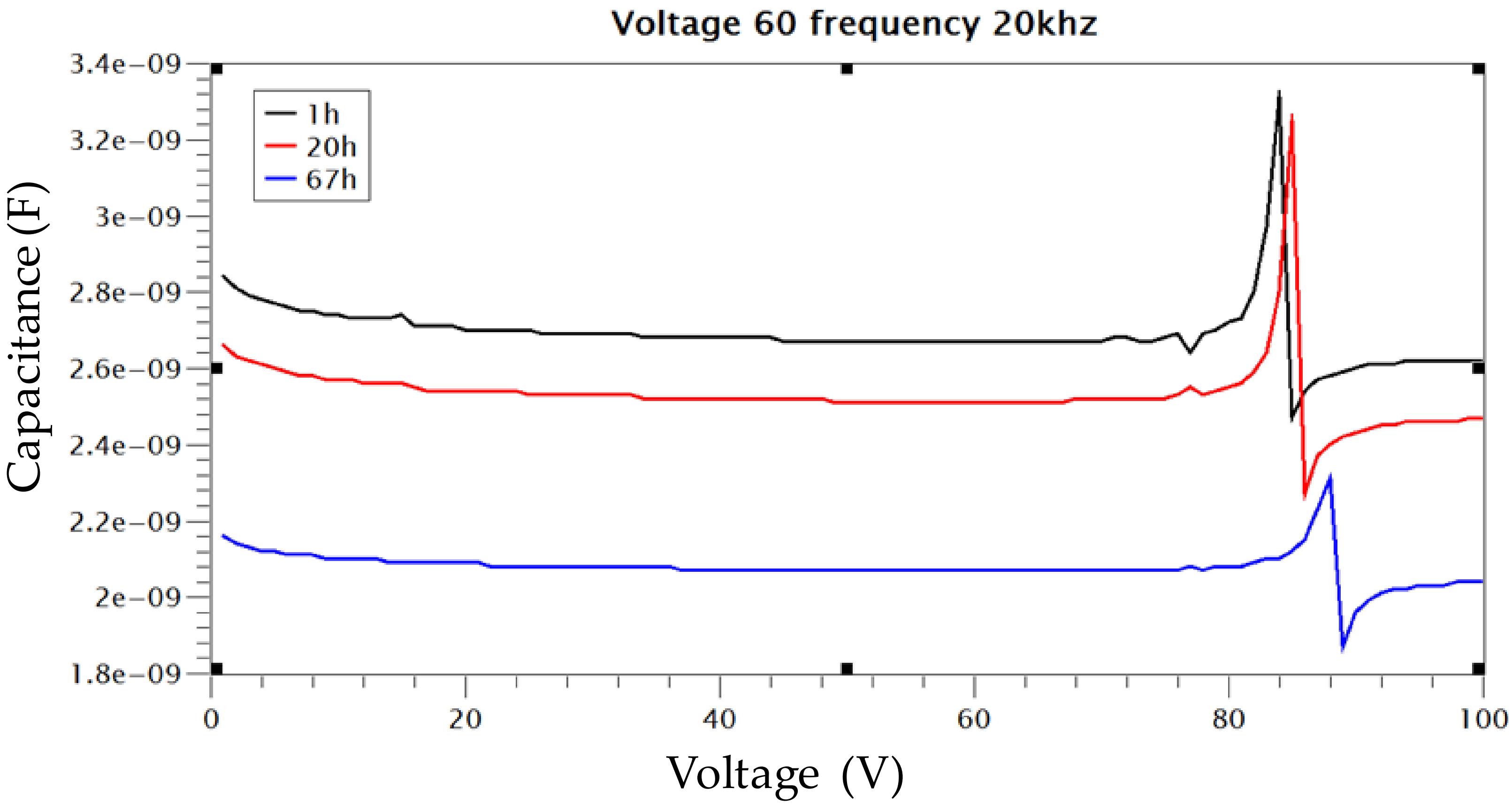
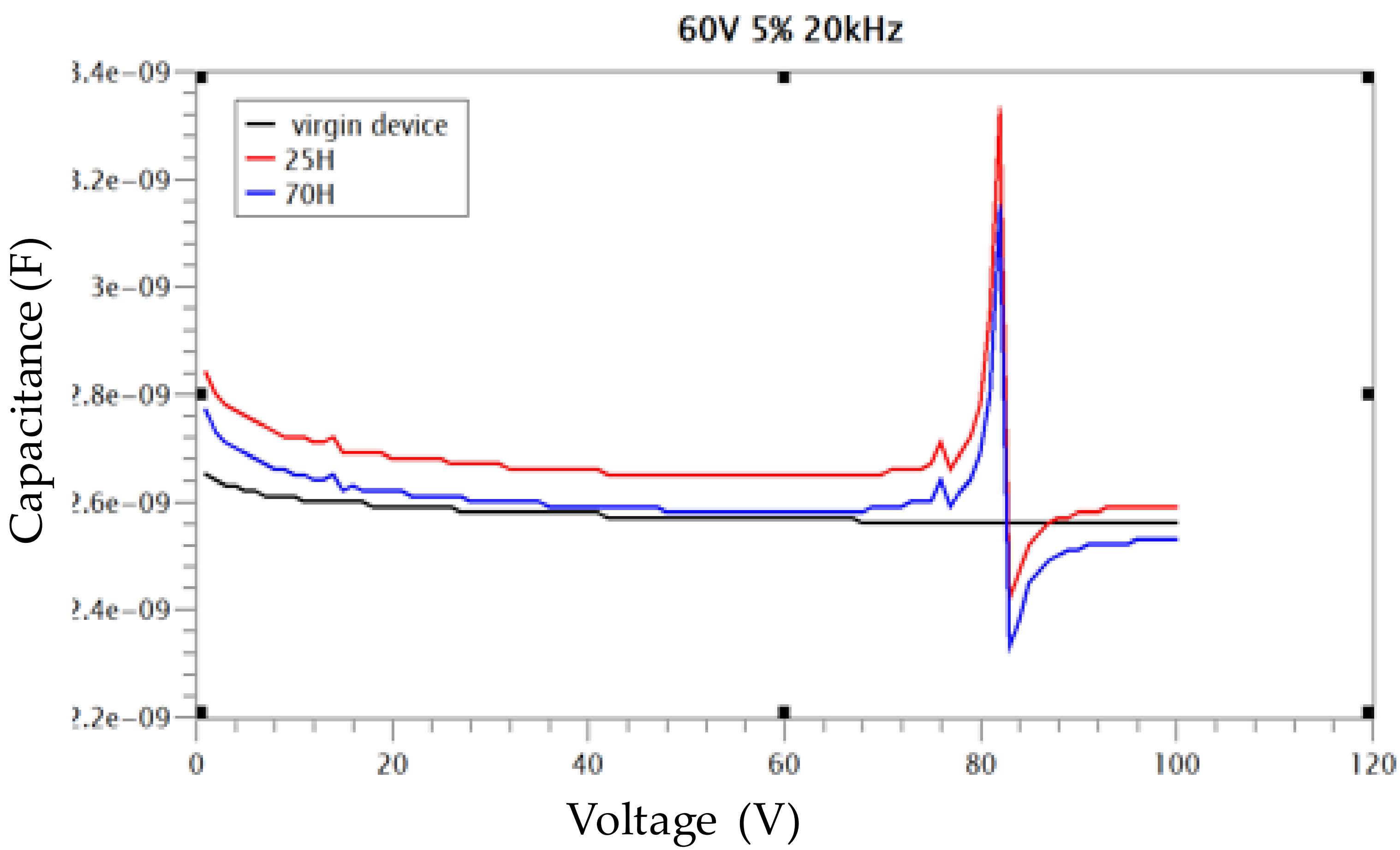
Characterization after several hours of cycling



To check the behavior of the device in time the capacitance measurement was performed at given time intervals.
As the time proceeds, the capacitance decreases.
It can be due to a residual polarization in the device.

A workaround for the time-varying behavior



An input including a slightly negative value (-5% Vmax) is used to overcome the residual polarization (input frequency is held as constant).

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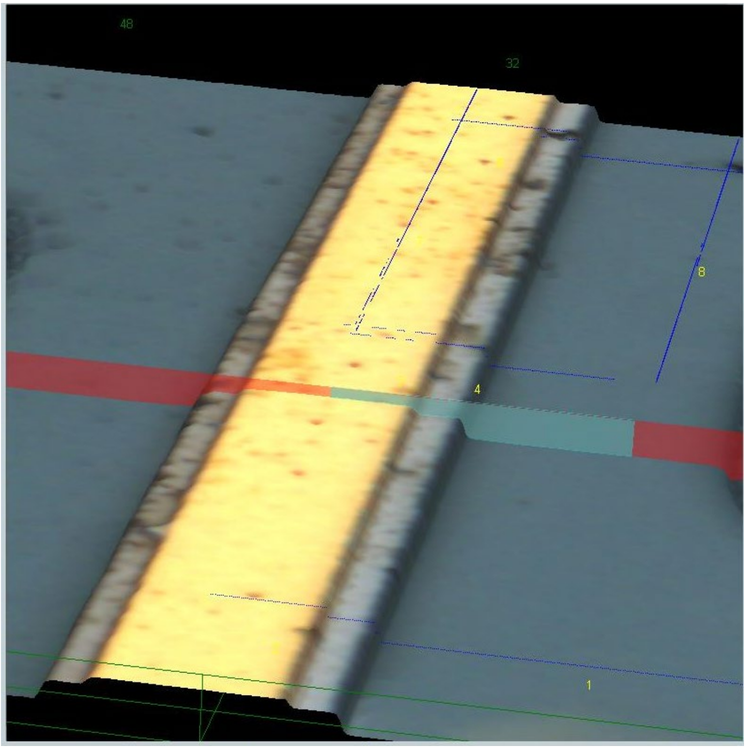
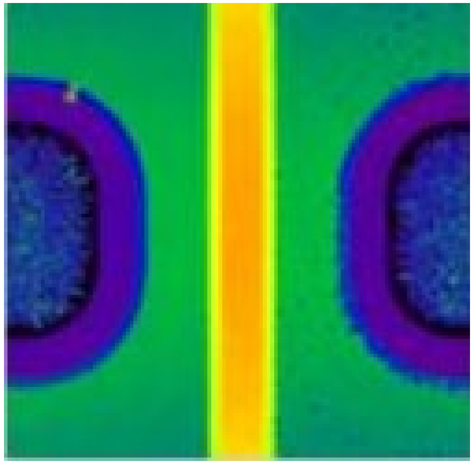
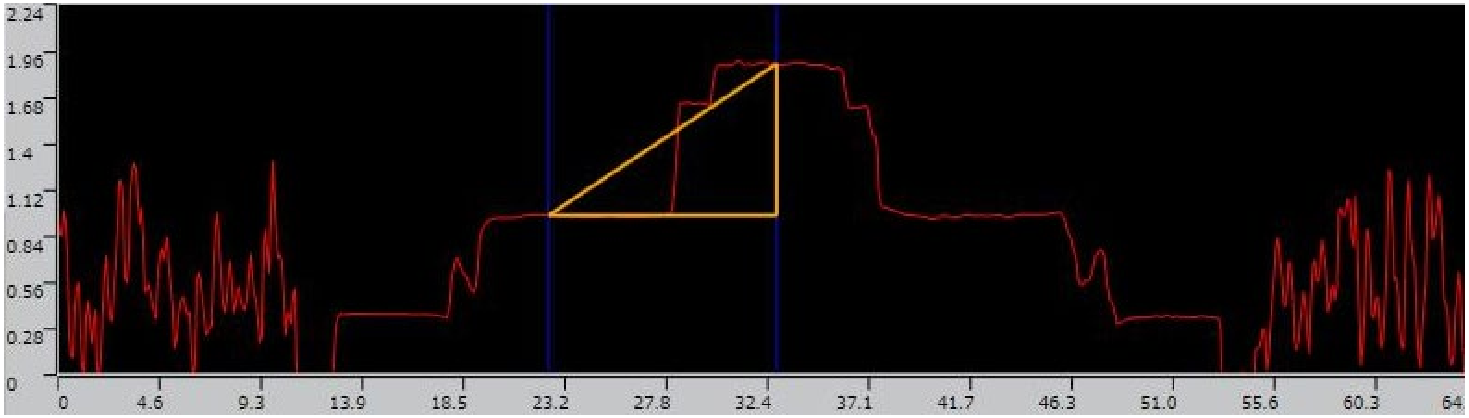
Fatigue degradation of the layered thin film





Heights (in false color)

After 60-hours cycling at 20 kHz the layered thin film evidenced degradation that can be captured by optical measurements and compared with the virgin state.



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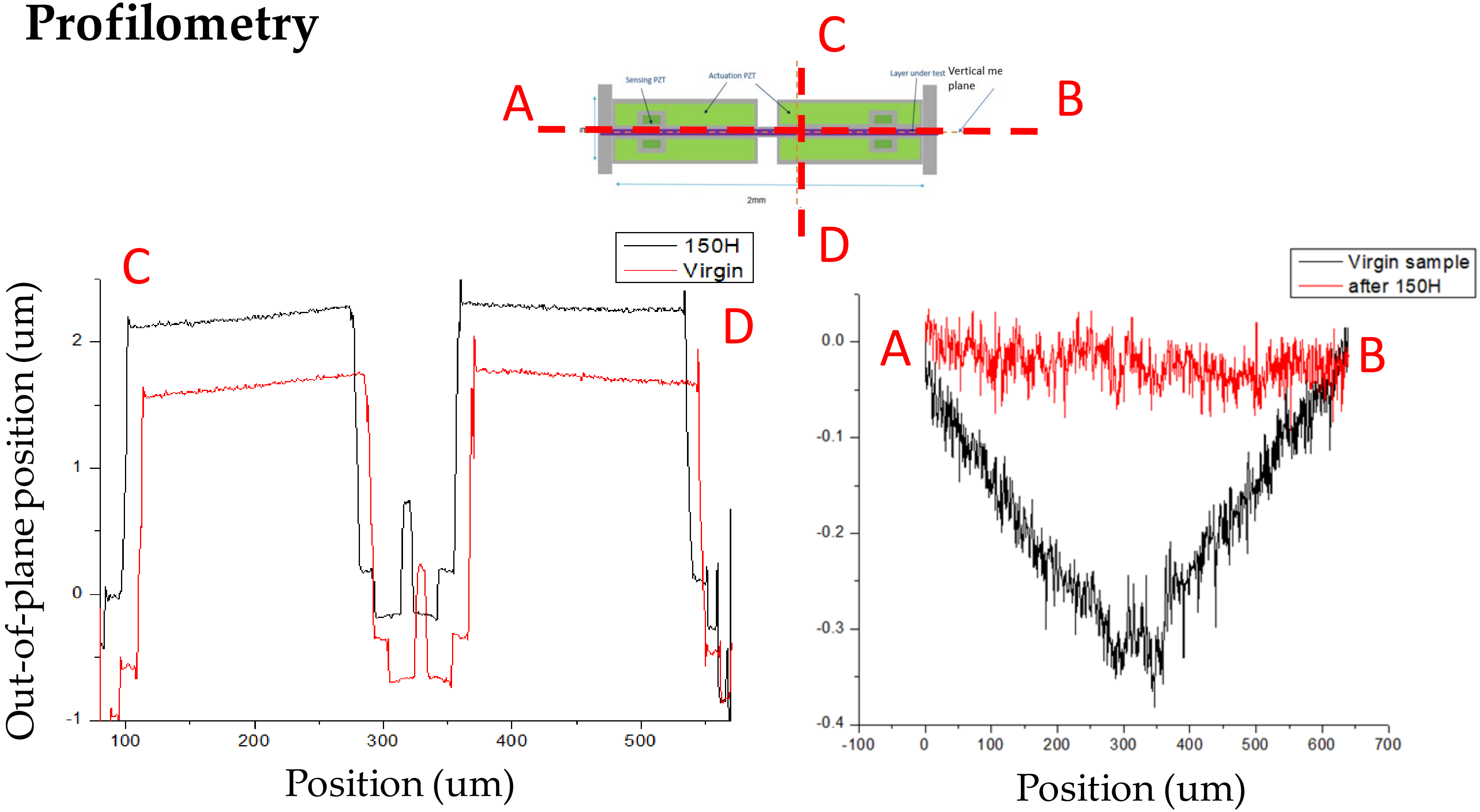
Profilometry



(Left) horizontal and (right) vertical profiles measured with a confocal microscope of the (red) virgin device and (black) after 150 hours cycling.

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Conclusions and future work

A piezoelectric micromachine was produced and tested for fatigue loading of layered thin films.

The behavior under several conditions (virgin state, after cycling) was characterized by capacitance vs frequency response.

The degradation of the layered thin film can be assessed via image acquisition of the metal surface that shows voids and a rough appearance after several hours of cycling. Frequency, maximum load (i.e. input voltage) and stress ratio were found to influence the response.

A re-design of the on-chip device is also ongoing, in order to also carry out quantitative evaluations.

Some references

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