ESRF	**Experiment title:** Investigation and mapping of residual stresses in RF-switch MEMS devices	**Experiment number**: 26384
Beamline: ID01	**Date of experiment**: from: 20/04/2011 to: 27/04/2011	**Date of report**: 04/08/2011
Shifts: 18	**Local contact(s)**: Gerardina Carbone	*Received at ESRF:*

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Report:

Aim of the experiment:

The objective of this experiment was to investigate the possibility of using the micro-beam x-ray diffraction technique in order to measure the residual stresses in Radio Frequency Micro-Electro-Mechanical System (RF-MEMS) devices. More precisely the experiment aimed at determining local crystalline properties and spatial mapping of the residual stresses occurring within the membrane of RF-MEMS under various fatigue conditions andunder operating conditions.

First, we expected to identify specific critical positions in the membrane which show high residual stress. Secondly we wanted to establish a correlation between the local residual stresses and the fatigue of the membrane. These results would bring valuable information on the mechanical behaviour of the membrane in devices and it is also expected that the studies can play a key role in the improvement of the fabrication process of the next generation RF-MEMS devices[1,2].

Experimental conditions:

The x-ray beam of energy E= 9.8 keV was focused using Be- compound refractive lenses (CRLs) to a size of ~5 μm × 5 μm (FWHM). The rather large beam size was required due to the particularity of the sample: the membrane consisting of a pattern of holes with a diameter of a few μm. The choice to investigate locally the properties of the membrane was carried out by analysing an area of a few 10 μm^2 located at strategic positions on the membrane (corners, edges, centre, ...). The experiment has been satisfactorily performed with this particular set-up and under appropriate conditions.

A bidimensional detector (Medipix) was used for this experiment. The setup was greatly simplified by using this detector: better statistics was obtained (measuring diffraction rings) and a full 2θ curve is measured in one shot. 4 Bragg angles - 2 for Au and 2 for TiW- are needed to determine the residual stress with the $\sin^2 \psi$ method. Moreover the $\sin^2 \psi$ method needs the measurement of each diffraction ring on a wide range of ψ angle. The trajectory of the detector was calculated in order to follow the Au and TiW diffraction rings for ψ from 0° to 70°.

A θ-2θ scan was first performed to determine the 2θ Bragg angles of Au (111), Au(200), TiW(110) and TiW(211) as specified previously. The samples were pre-positioned into the x-ray beam using a high resolution optical microscope pointing at the center of the diffractometer. The diffraction angles were set in a such way to scan at least one of the Bragg peaks mentioned above, and the sample position was laterally scanned (x and y translations) while recording an image at each point (Bragg peak intensity). For the very same object, several probe signals (characteristic Bragg peaks) can be recorded on the same image of the area detector. The resulting xy map (figure 1) allows the precise positioning of the investigated point in the X-ray beam. We assumed that the membrane is totally symmetric. Measurements have then been performed at 10 selected positions on one quarter of the membrane. Then, at each of the 10 points of interest, a full diffraction ring is collected with the detector.

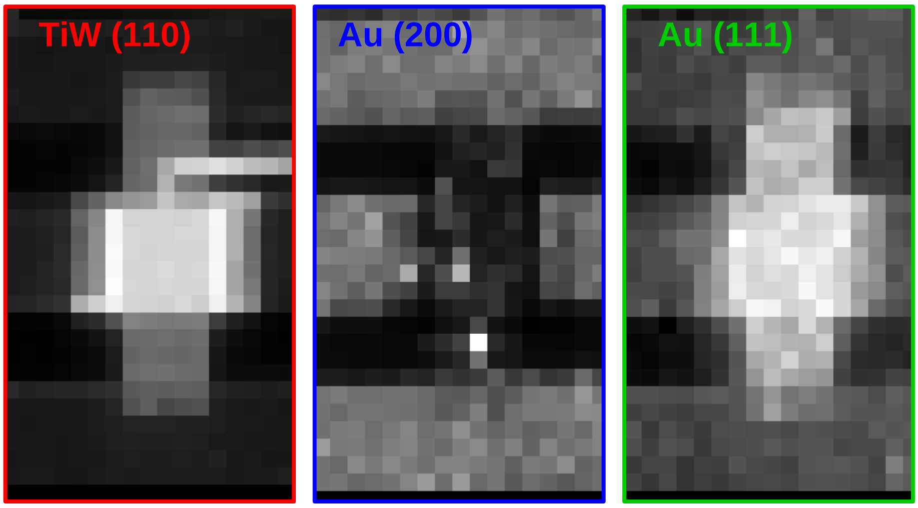

Figure1 : 2-dimensional maps performed on the virgin RF-MEMS at the characteristic peak of TiW(110), Au(200) and Au(111)

Thanks to the use of the 2-dimensionnal detector we were able to carry out exhaustive measurements for 5 different cases:

(a) Reference powers CeO_2
(b) RF-MEMS without membrane
(c) Virgin RF-MEMS: this device has never been activated
(d) RF-MEMS activated prior the experiment (2 situations were studied)
(e) RF-MEMS activated by the application of a constant DC voltage (membrane pulled down), and after the activation (membrane released)

In order to eliminate possible geometrical errors (mostly due to the diffractometer angular movements), a CeO_2 reference powder was used and images of several CeO_2 diffraction rings were recorded. By grouping and converting all these data into a single 2θ–ψ dataset it is possible to extract 'defects' of the diffractometer movements - indeed the scattered signal is expected to appear along perfectly circular rings. Any deviation from the circle shape is attributed to the instrument and corrected. The geometrical corrections (radial and angular positions of the detector with respect to the incomming beam direction and the illuminated area on the sample) are taken into account according to the procedure mentioned above.

Figure 2 presents results obtained at the TiW (110) peak on the RF-MEMS before the activation. By comparing the CeO2 reference curve with the measured TiW (110) curve on the RF-MEMS membrane, we can conclude that for the bi-metallic membrane, the TiW layer is under stress.

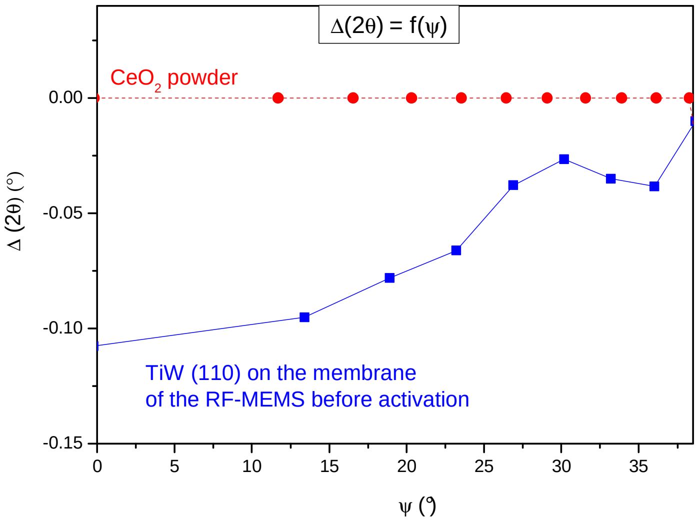

Figure 2 : Deviation to the TiW (110) Bragg angle measured on the membrane of the RF-MEMS before activation (blue line)- and reference CeO2 powder (red line) (deviation to this curve is directly attributed to residual stress in the layer)

Note that in this case the measurement of the diffraction ring is done **without moving the sample** (not in angle nor in lateral position) but, it is done by accessing the diffraction ring using the angular movements of the detector (δ and γ) and by applying the corrections deduced from the measurement of the reference CeO_2 powder. In this way, for the whole measurement, we ensure the illumination of **the *very same area of the sample***, which is difficult or almost impossible to achieve with µm focused X-ray beams if the sample ψ angle has to be moved (0-90° range) for the classical $\sin^2\psi$ method.

The initial results presented here show the viability of this technique for stress measurement of the membrane structures. However, work is still under progress to fully exploit the measurement that has been carried out for each of the mentioned cases. The interpretation and comprehensive exploitation of the measured data is carried out using an in-house procedure and this can be a particularly fastidious process. However, we do expect to be able to reconstruct the residual stress mapping of the membrane in the different cases once the measured data have been fully explored.

Conclusion:

In summary, we can say that the <u>micro-beam x-ray diffraction technique can be used to measure the residual stress in micronic devices such as RF MEMS. The proposed experimental set-up, conditions and good performance of the beam line have validated the feasibility of this investigation in accordance with the initial objectives. A more thorough understanding of the stress phenomenon can be obtained once the measured data have been fully exploited.</u>

References:

[1] B. Lakshminarayanan *et al.* IEEE Transactions on Microwave Theory and Techniques, Vol. **56**, No. 4, April 2008
[2] S. Rigo *et al.* Microelectronics Reliability, Vol.43, p1963, 2003