

**“PRO INVENT” RESEARCH CONFERENCE–24.03.2016**

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**Advanced design of micromembranes  
with multiple degrees of freedom  
for optical MEMS applications  
(multiDOF)**

**PN-II-RU-TE-2014-4-1271 - 2015 - 2017**

**Project manager: Prof.dr.ing. Marius PUSTAN**

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<http://minas.utcluj.ro>

## Project team:

Prof.dr.ing. Marius PUSTAN, **Project Manager**

Prof.dr.ing. Corina BIRLEANU, **Experienced Researcher**

Prof.dr.ing. Cristian DUDESCU, **Experienced Researcher**

Assist.dr.ing Violeta MERIE, **Research Assistant**

Assist.dr.math. Florina RUSU, **Research Assistant**

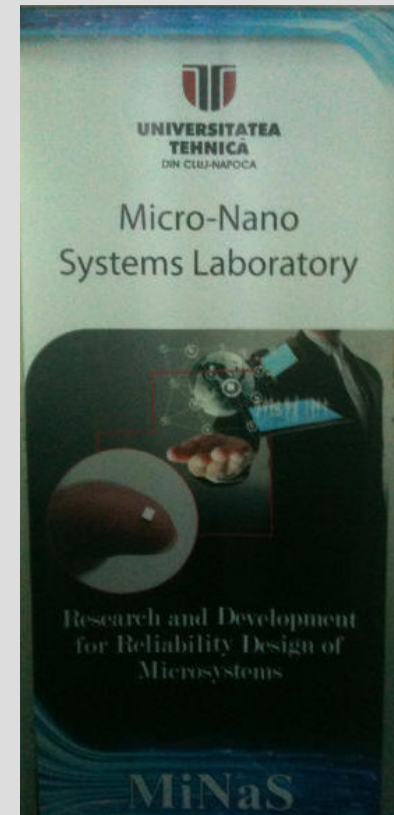
Asist.dr.ing. Radu CHIOREAN, **Research Assistant**

PhD Student Ioana PINTEA, **Research Assistant**

## MiNaS Laboratory: What are we doing?

- Research & Development for reliability\* design of MEMS.
- Mechanical and tribological characterization of MEMS.

**\*Reliability is the probability that a component will satisfactorily perform its intended function for a specified period of time**



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## Representative results of Principal Investigator and the research team

### Publications (since 2010)

- Papers in ISI journals: **20**
- Conferences (ISI, Scopus): **18**
- Book chapters: **1**



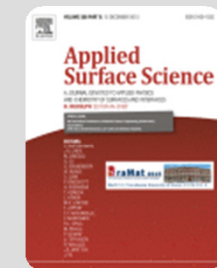
### Representative projects:

**PN-II-RU-TE-2011-3-0106:** Nanomechanical and nanotribological characterizations for reliability design of MEMS resonator 2011-2014

**FP7-ERA.NET:** 3-Scale modelling for robust design of vibrating micro sensors (*3SMVIB*). 2012-2015

**European Space Agency ESA – CDI STAR nr. 32:** Reliability design of RF-MEMS switches for space applications. 2012-2015

**European Space Agency ESA – CDI STAR nr. 97:** Tribomechanical Characterization of MEMS Materials for Space Applications under harsh environments 2013-2016

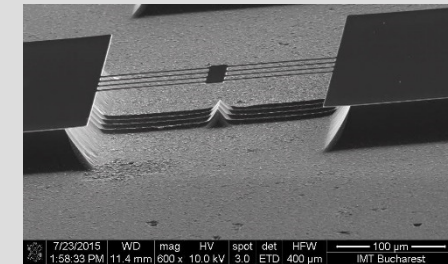
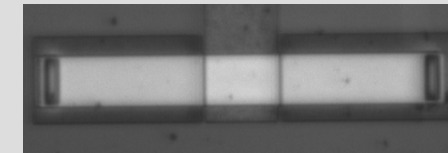
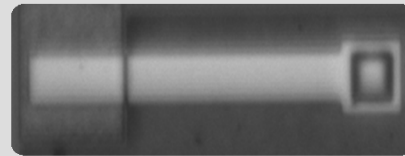
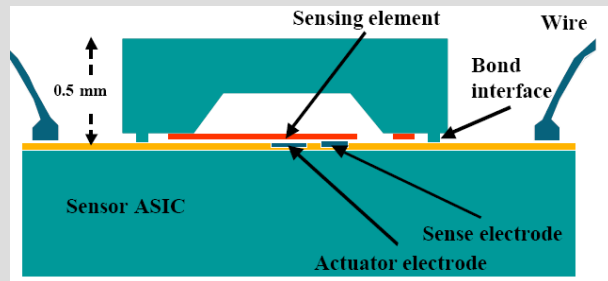


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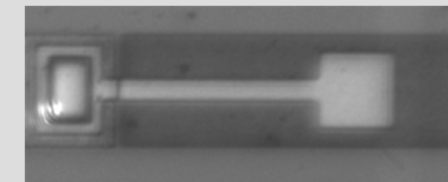
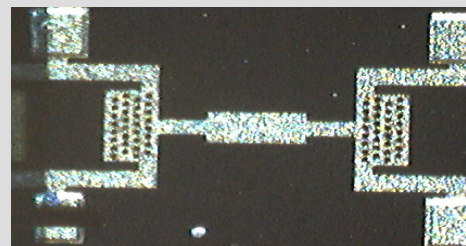
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## **MEMS** = micro-electro-mechanical systems

devices containing extremely small mechanical elements, which are usually integrated with electronic processing circuits



**Could be:** Microsensors, Microactuators, RF-MEMS, Optical MEMS, Microfluidic MEMS, Bio MEMS, Mass detection sensors ...

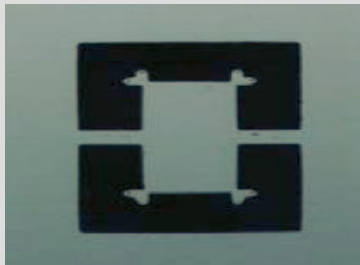


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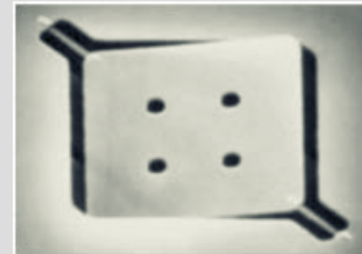
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## Optical MEMS

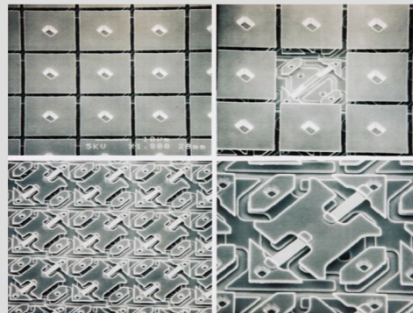
### Torsion micro-membranes from optical applications (optical signal processing)



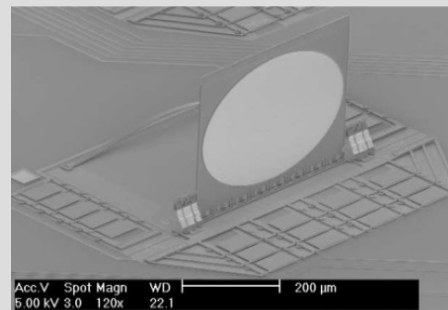
Orientation of the signal by rotating the micro membrane with  $10^\circ$



Possibility of linear displacement and angular out of plane movement



Optical beam redirecting in order to create images of great clarity, manufactured by Texas Instruments Inc., (Digital Mirror Devices)



MEMS optical switch, actuated by a control mechanism on a distance of  $22\mu\text{m}$  which leads to an inclination of micro-mirror up to  $90^\circ$ . (manufactured by AT & T Lab)

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## Context of optical MEMS

### *Technically demanding applications:*

- internet network systems through fiber optics; digital scanning systems based on optical mirrors for switching and transmission systems for the optical signal
- medical devices, micro-optical scanners have resulted in three-dimensional scanning endoscopic systems
- variable optical attenuators, optical spectrometers, code readers, etc

### *Challenges for mechanical elements:*

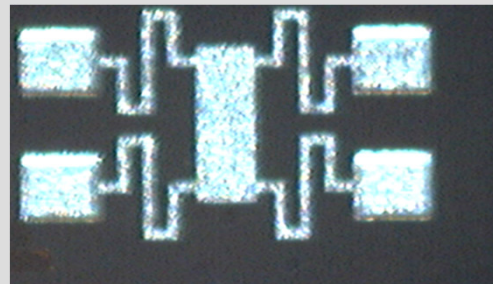
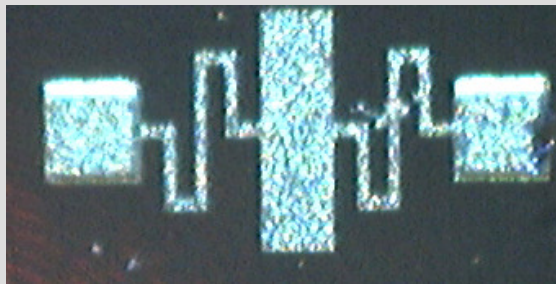
- **Mechanical properties of micro-membranes materials at microscale** must be well known in order to assess the behaviour of the system (eg, a micro optical mirror) during operation as well as the lifetime
- MEMS micro membranes must be designed in such a way as to **fulfill the functional role in a relatively short time** (milliseconds or pico-seconds), with a **low energy consumption** but also high mobility in different planes.
- **Reliability and lifetime** of the entire system depends on the **behavior of flexible mechanical elements** (influenced by the state of stress, fatigue life, deformations level) and also the employed materials properties (hardness, elasticity module, coefficient of thermal expansion).
- **Temperature** has a negative effect on material properties with influence on static and dynamic response of micro membranes

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## Project main objective

- **Developing of reliable micro-membranes with multiple degrees of mobility and undergoing low mechanical stress.**



Micro membranes with multiple degrees of freedom

## Contributions to the development of knowledge:

- Determining the mechanical properties of MEMS materials from optical applications and implementation of a database for the design;
- Development of complex configurations of micro membranes with multiple degrees of mobility, reliable and with high durability;
- Development of analytical relations necessary to determine the static and dynamic response of the micro membranes in different planes;
- Comparative analysis of several types of micro membranes geometries in order to adopt the optimal solution.

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## Project objectives

**O1. Investigations on materials used to fabricate MEMS micro-membranes for optical applications** // Investigation technique: Nanoindentation module of AFM, thermal chamber

- (1) Analysis of MEMS materials, their usage limits and requirements for optical applications;
- (2) Experimental determination of **mechanical properties** of materials used in MEMS optical applications
- (3) Experimental investigations of the **temperature influence on mechanical properties** of materials used in MEMS optical applications;
- (4) Opening the project WEB page including an **e-database** about the behavior of material properties for different temperatures.

**O2. Theoretical and numerical analysis of static and dynamic response of micromembranes:**

- (5) **Design of micro-membranes** with multi degree of freedom characterized by different geometrical configurations of hinges;
- (6) Development of **analytical models** in order to determine the mechanical response of micromembranes for different displacements;
- (7) Analysis of the **stress distribution** in hinges using the Euler-Bernoulli model or the Timoshenko model;
- (8). **Finite Element Analysis (FEA)** of micro-membranes for in-plane and out-of-plane motion and their optimization.

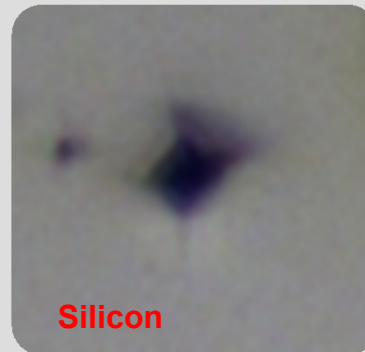
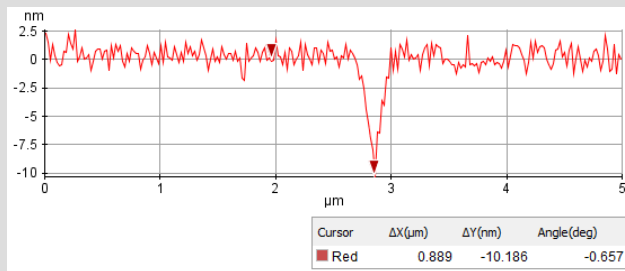
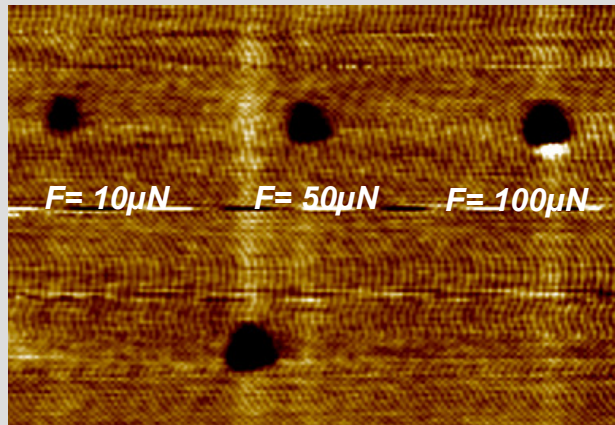


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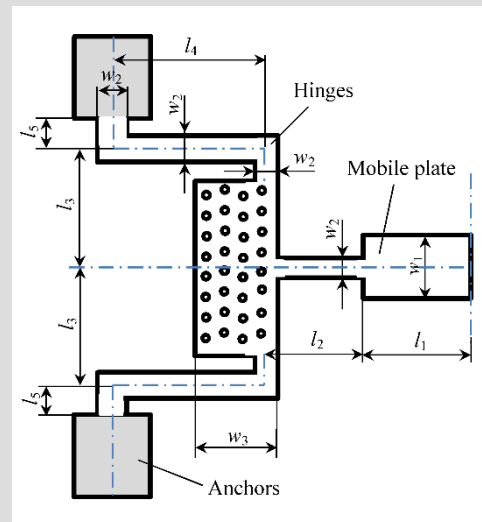
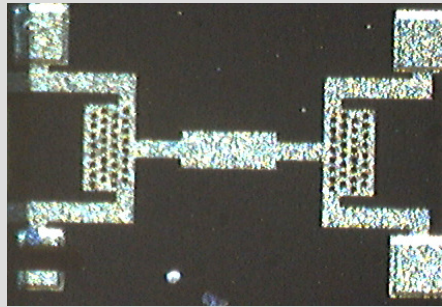
## Experimental techniques: AFM Nanoindentation & Hardness measurement

Determination of the Young’s modulus and the hardness of MEMS materials



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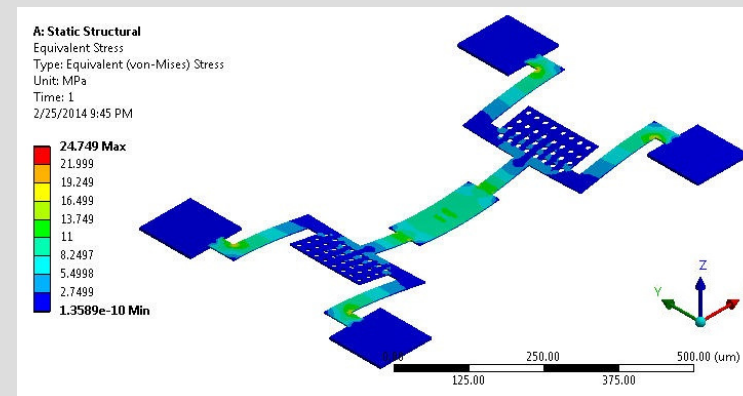
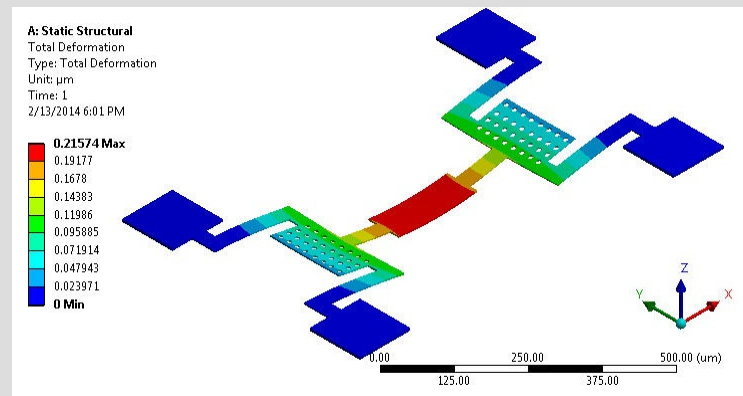
## Analytical models & Finite Element simulations:



$$S_b = \frac{1}{E} \left( \frac{l_5^3 + 6A_6 l_5^2 + 12A_6^2 l_5 + l_4^3 + 3(A_1 - l_1 - l_2 - l_4)l_4^2 + 3(A_1 - l_1 - l_2 - l_4)^2 l_4}{6I_5} + \frac{l_3^3 + 3(2A_6 + l_5)l_3^2 + 3(2A_6 + l_5)^2 l_3 + l_2^3 - 3(A_1 - l_1)l_2^2 + 3(A_1 - l_1)^2 l_2 + l_1^3 - 3A_1 l_1^2 + 3(A_1)^2 l_1}{6I_3} + \frac{l_4^3 + 3(A_1 - l_1 - l_2 - l_4)l_4^2 + 3(A_1 - l_1 - l_2 - l_4)^2 l_4}{6I_4} + \frac{l_2^3 - 3(A_1 - l_1)l_2^2 + 3(A_1 - l_1)^2 l_2 + l_1^3 - 3A_1 l_1^2 + 3(A_1)^2 l_1}{3I_2} + \frac{l_1^3 - 3A_1 l_1^2 + 3(A_1)^2 l_1}{3I_1} \right)$$

$$S_t = \frac{1}{G} \left( \frac{(l_1 + l_2 + l_4 - A_1)^2 l_5}{2I_{p5}} + \frac{(2A_6 + l_5)^2 l_4}{2I_{p4}} + \frac{(l_1 + l_2 - A_1)^2 l_3}{2I_{p3}} \right)$$

$$k = \frac{2}{S_b + S_t}$$



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## Project objectives

**O3. Manufacturing of micromembranes with high mobilities** // support from IMT Bucharest

(9) **Identifying of the adequate MEMS manufacturing process** in order to avoid the membranes prestress;

(10) Design of the masks and **fabrication** of micromembranes with different geometrical configurations and multiple degrees of freedom;

(11) **Measuring of the real dimensions** of fabricated micromembranes, also their **structural and morphological analysis**; (12) Results disseminations.

**O4. Experimental investigations on the mechanical behavior of MEMS micro-membranes** // Investigation technique: **AFM, vibrometer, AFM spectroscopy in point**

(13) Analysis of the **dynamic and static response** of investigated micromembranes in different planes (stiffness, compliances, displacement, resonant frequency);

(14) Experimental determination of the stress - strain and fatigue analysis;

(15) Measurement of the adhesion between the micromembranes and substrate;

(16) Analysis of the thermal effect on mechanical response and adhesion force.

**O5. Team training activities and dissemination of project results:**

(17) Participation of the team members to MEMS training activities;

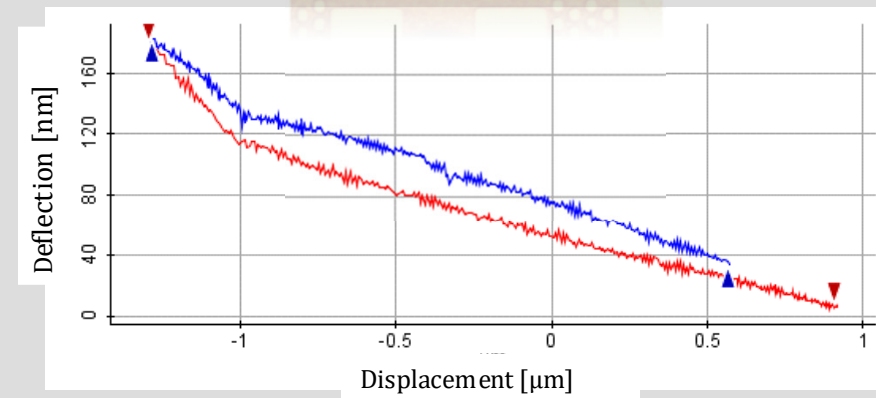
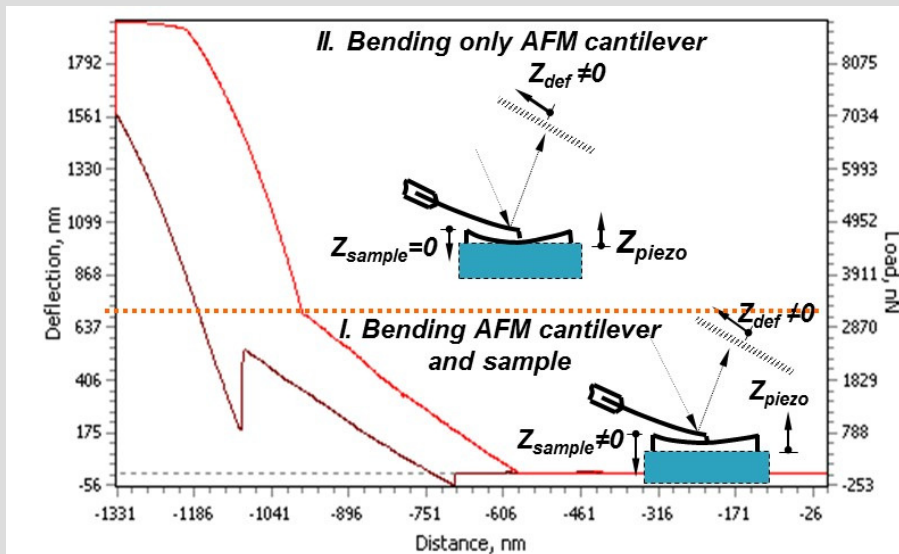
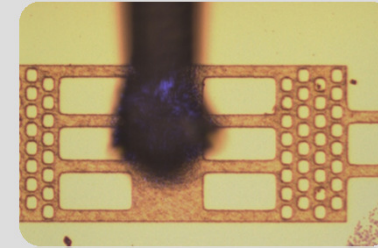
(18) Updating of the project WEB page;

(19) Participation to international conferences and publishing of scientific papers in prestigious journals;

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## Experimental techniques: AFM stiffness measurement

$$\left. \begin{aligned} F &= k_{\text{cantilever}} \cdot Z_{\text{def.II}} \\ Z_{\text{sample}} &= Z_{\text{piezo}} - Z_{\text{def.I}} \end{aligned} \right\} \text{Stiffness of sample: } k = \frac{F}{Z_{\text{sample}}}$$



AFM experimental curve of a flexible structures

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## Milestones

- The **first milestone** (M1) comes after the MEMS materials characterizations from optical application and micromembranes design. At this point, the project team will have defined the specifications to fabricate micromembranes with multiple degrees of freedom (DoF) and to provide technological report to manufacturer.
- The **second milestone** (M2) comes after the micromembranes fabrication and its reliability testing. At this point the research team should finish the failure analysis of samples performed in laboratory and start the final implementations.

## Deliverables:

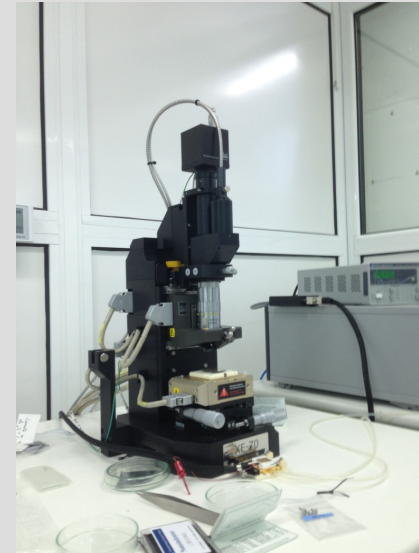
- Database with material properties used in optical MEMS and their dependence as a function of temperature.
- Database with geometrical configurations of micromembrane and analytical formulas to compute their responses in different planes.
- Optical micromembrane fabrication
- Publication of scientific papers in ISI journal and participation international conference.
- Project WEB page;

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## Available resources:

- Multifunctional AFM XE70, with nanoindentation module, contact, lateral force and dynamic analysis;
- Temperature control equipment from  $-10^{\circ}\text{C}$  to  $180^{\circ}\text{C}$ ;
- Microscope AFM NT206;
- Optical measuring system of displacements based on digital image correlation;



## Access to third parties facilities:

- Lithography equipment for MEMS (collaboration – IMT Bucharest);
- UHV e-beam evaporation 6kW,  $10^{-7}$ Torr; 20 -  $2000^{\circ}\text{C}$ ;
- Spectrometer QMS-200;
- Polytec vibrometer (collaboration - University of Liege).

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## Submitted papers:

1. M. Pustan, C. Birleanu and C. Dudescu, ***Material nanocharacterization and analysis of the adhesion effect in MEMS optical applications, NanoSEA 2016***
2. M. Pustan, C. Birleanu and C. Dudescu, ***Investigation on the contact behavior of MEMS micromembrane with serpentine hinges, ROTRIB 2016***
3. Marius PUSTAN, Cristian DUDESCU, Corina BÎRLEANU, Florina RUSU; Radu CHIOREAN; Stefan CRACIUN, ***Effect of geometrical dimensions on the tribomechanical response of a gold micromembrane with bent beam hinges, ACME 2016***

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**Thank you for your attention!**