MECHANICAL AND TRIBOLOGICAL CHARACTERIZATION OF MEMS

HABILITATION THESIS - ABSTRACT

Microelectromechanical systems (MEMS) are a class of devices characterized both their small size and by the way in which they are fabricated. MEMS devices are considered to range in characteristic length from one millimeter to one micrometer, many times smaller than the diameter of a human hair.

The habilitation thesis "Mechanical and Tribological Characterization of MEMS" presents the scientific and professional achievements of the author from the period 2006 - 2015 in the field of reliability design of MEMS. This research field implemented by the author is based on two postdoctoral positions. The first one developed at Warsaw University of Technology during 2006-2007 for mechanical and tribological characterization of microsystems. The second one, from 2009 to 2011 was done in University of Liege for experimental investigations of the dynamic behavior of MEMS. As a result of these activities and based on significant research projects the author accredited at Technical University of Cluj-Napoca, the Laboratory of Micro and Nano- Systems (http://minas.utcluj.ro).

Two of the main failure causes of MEMS are fatigue and stiction. Fatigue is an important problem in MEMS oscillators those operate under high cycle loading. Stiction is an unavoidable failure mode in MEMS with direct contact between flexible component and substrate. The reliability design of MEMS requires accelerate mechanical and tribological testing on the failure modes of structure for proper lifetime prediction.

The habilitation thesis is structured on three scientific sections including mechanical and tribological characterization of MEMS. These scientific sections are accompanied by the other sections those provide details about the summary of author activities and contributions of scientific and professional prestige. Future scientific, professional and academic development plan is included at the end of thesis.

The section "*Mechanical characterization of MEMS components*" presents studies performed on the mechanical behavior of flexible structures such as microcantilevers, microbridges and micromembranes. These are MEMS components that can operate either individually or can be incorporated into more complex configurations. The mechanical characteristics under investigations are stiffness, modulus of elasticity, strain and stress.

Microcantilevers (free-clamp beams) are used as sensing/actuation devices in a vast range of applications. A microcantilever can be utilized either in the static regime, in order to measure deflections or rotation, or in the oscillating mode, when the modal frequencies are monitored. Microbridges that are fixed at both ends are used in MEMS applications such as filters and switches. Micromembranes used in optical and communication applications with different configurations of hinges are analyzed in order to determine the static response under an applied load. Widely used in switches, these micromembranes are deflected until substrate in order to close a circuit. The adhesive force between micromembrane and substrate depends on the mechanical restoring force given by the hinges stiffness.

Multilayers MEMS components are usually used in microtransduction for actuation and sensing. One layer achieves the structural and elastic recovery function and the other layers are active parts by deforming under actuations. The studies of mechanical

characteristics of flexible bilayer microcantilevers fabricated in the SU8 polymer with a reflective nano-metallic layer on top are also presented in this section.

There are MEMS applications where the system operates under a thermal field. To improve the reliability design of such flexible components, the analysis of temperature effect on the tribological and mechanical behavior of microcomponents is developed and included in this section. A nonlinear variation of the bending stiffness of a microcantilever as a function of temperature is determined. Finite element analysis is used to estimate the thermal field distribution in microcantilever and the axial expansion.

The other scientific section "*Dynamical behavior of MEMS*" presents analysis of MEMS resonators and their behavior under various operating conditions. Many of the MEMS industrial applications require vibrating components that operate under a high quality factor and small energy dissipation during oscillations. The mechanical behavior of resonators strongly depends on the operating conditions. To improve the reliability of MEMS resonators, the effect of operating conditions on the dynamical response of vibrating components has to be accurately determined.

In this chapter, experimental investigations are performed to determine the resonant frequency response and to estimate the loss of energy in MEMS resonators. Most of the MEMS vibration sensors have polysilicon structure as the sensing element. Even these components are simple geometrical structures their dynamical behavior is needed to be more accurate investigated. Analytical models accompanied by experimental tests on the dynamical response and the loss of energy on vibrating microstructures are presented.

One of the most important applications of MEMS resonators are mass-detection for chemical and biological applications, radio frequency applications, automobile industry and aircraft conditions monitoring or satellite communications.

For cyclic motions of a structural material, significant heat generation occurs and energy dissipation is produced due to an energy loss mechanism internal to the material. The temperature gradient generates heat currents which cause increase of the entropy of the resonator and lead to energy dissipation. It is desired to design MEMS resonator with loss of energy as little as possible. The loss of energy in MEMS resonators is evaluated considering the frequency response curves and measuring the bandwidth of oscillations.

The last scientific section "*MEMS material characterization and tribological investigations*" presents the analysis of adhesion force and friction. Adhesion force depends on the operating conditions and is influenced by the contact area. The roughness has a strong influence on the adhesion because the contact area between components increases if the roughness decreases. The experimental tests are developed using the spectroscopy in point of AFM. The dimensions of the AFM tip and its coated material have influence on adhesion. Numerical computation of adhesion force is developed using the JKR and DMT models. The temperature effect on MEMS materials properties is analyzed using a temperature control system. The changes of the mechanical and tribological properties of MEMS material as a function of temperature are investigated. The coupling of the strain field to a temperature field provides an energy dissipation mechanism that allows the material to relax. In the case of investigated MEMS materials, the relaxation strength to be considered is that of the modulus of elasticity with influence on contact stiffness and hardness. The direct measurement of the temperature effect on tribological and mechanical behavior of MEMS materials is important to improve the reliability design of MEMS devices.