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הפקולטה להנדסה
ע"ש איבי ואלדר פליישמן
אוניברסיטת תל-אביב

0540-6606
תכן ומידול של מערכות זעירות
Design and Modeling of Microelectromechanical Systems (MEMS)

Lecturer: Prof. Slava Krylov

Classes: Thursday 16^{00}-19^{00} Online

Hours: after the class or by appointment

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Grades: Project-50% Final Exam - 50%

Texbooks :

S. Senturia, Microsystems Design, Kluwer academic publishers, 2001.

J.A. Pelesko and D.H. Bernstein, Modeling of MEMS and NEMS, CRC Press, 2002. (available at CRC Eng. Handbooks Online).

M. I. Younis, MEMS Linear and Nonlinear Statics and Dynamics, Springer, 2011.

Additional references:

M. Gad-el-Hak, MEMS Handbook CRC Press (available at CRC Eng. Handbooks Online).

J. J. Allen, Micro Electro Mechanical System Design, Boca Raton: Taylor & Francis, 2005.

N. Lobontiu, E. Garcia, Mechanics of Microelectromechanical Systems, New York: Kluwer Academic, 2005

N. Maluf, An introduction to Microelectromechanical Systems Engineering, Boston: Artech House, 2000.

Class #	Outline
1	Brief history and main applications of MEMS. Main fabrication steps-thin film deposition, lithography and pattern transfer, etching. Integrated processes. Surface and bulk micromachining. Influence of the fabrication process on the structure geometry and material properties.
2	Electrostatic actuation. Advantages and disadvantages of electrostatic actuation. Differential form of Gauss's law. Scalar potential. Poisson and Laplace equations. Boundary value problem of electrostatics. Surface distribution of charges. Electrostatic potential energy. Force acting on the surface of a conductor. Formulation of a coupled electro-mechanical problem and a general scheme of its solution. Example of a coupled electromechanical problem – one-dimensional case. Electrostatics of macroscopic media, dielectrics. One-dimensional electromechanical problem in the case of presence of a dielectric layer.
3	Main types of electrostatic devices. Parallel-plate capacitor, spring-capacitor model. Pull-in instability. Tilting electrostatic actuators (micromirrors). Linear comb drive actuator. Side pull-in instability. Influence of nonlinearity of the suspension. Design challenges of comb drive actuators. Vertical comb drive actuator.
4,5	Continuous systems - illustrative example of an elastic membrane (string) actuated by an electrostatic force. Small aspect ratio approximation of the electrostatic pressure. Exact solution, equilibrium curves for the membrane. Pressurized membrane under distributed electrostatic force, bistability. Formulation of the coupled electromechanical problems for beams and plates.
6,7	Reduced order (RO) modeling of electrostatic structures. Rayleigh-Ritz and Galerkin methods. RO model of the elastic string under distributed electrostatic force, comparison with the exact solution, convergence of the RO models. Consistently derived lumped models. Cantilever and double clamped beams under distributed electrostatic force, initially curved beams, bistability. General approaches for solving coupled electromechanical problems in MEMS/NEMS, device and system level modeling. Use of commercial CAD packages for analysis of MEMS.
8-9	Dynamics of electrostatically actuated micro structures. Development of the equations of motion from variational principles. Dynamic stability (dynamic pull-in). Role of nonlinearity, Duffing equation. Parametric excitation of electrostatic structures, Mathieu equation. Actuation by self-excitation.
10	Role of damping in dynamics of microstructures. Squeeze film damping, Reynolds equation. Squeeze number, damping and stiffness dominated case, Knudsen correction, squeeze film damping in the case of low pressure environment.
11	Thermal actuation. Development of a model of a beam undergoing Joule heating. Bimorph and buckling-type actuators. Electrothermal tuning of electrostatic actuators. Electrothermal actuator as a flow sensor.
12-13	Inertial sensors, micro accelerometers and angular rate sensors (gyroscopes). Derivation of the governing equation of the accelerometer and micro gyro. Examples of architectures and design approaches. Design challenges. Noise.