Spring 2003 May 21, 2003

Prof. Cheng-Hsien Liu

**(Due-noon of June 12 for a CD including all your Final Exam File**

**(submit to TA- Kuang-Han Chu)**

**Due-noon of June 16 for your file on your web)**

**Delay policy- 10 points less/day for both part 1 and 2**

# PME5231 Final Exam

**(Part 1 takes 5% of your final grade. Part 2 takes 35% of your final grade.)**

**Part 1- For parallel-plate capacitive micro-actuators-**

**Question 1-1:** (40%) why don't we use charge control instead of voltage control?

**Question 1-2:**( 60%) Please give a design to let actuating distance overcome 1/3 of nominal plate separation.

**Part 2-Simulation of a Tunneling Accelerometer**

The side view of a MEMS tunneling accelerometer illustration with a simple feedback circuitry is shown in the following figure.

(a) The proof mass is made by a p-type (100) **200 mm-thick** Si wafer with a thin Cr/Au layer as proof mass electrode. The mass of Cr can be neglected compared with Au layer mass. The proof mass electrode and proof mass have the same area of 0.54 $cm^2$ and 0.8 cm long.

(b) The proof mass is 28.2 milli-gram. The referent frequency of proof mass is 100 Hz. The quality factor Q for the proof mass is 140.

(c) Unforced gap between proof mass electrode and deflection electrode is 34 μm. The tunneling tip heigh is exactly 31 μm.

(d) The relationship between tunneling current and tunneling gap is

$$I_t \propto V_B \times \exp(-a_I \sqrt{\Phi}\, x)$$

where $V_B$ is tunneling bias across the tunneling electrode gap, $\alpha_I$ is a constant, $a_I$ =1.025(Å$^{-1}$ eV$^{-0.5}$), and Φ is the effective work function of Au which is to be measured in this exam. $x$ is the tunneling gap.

(e) The gravity is ignored in this exam.

(f) The op-amp is modeled as a low pass filter with high DC gain

$$A_{op} = \frac{K_{op}}{a\,s+1} \quad \text{where} \quad K_{op} = 10^6, \quad a = \frac{1}{20 \times p}$$

**Question 2-1:** **(5%)**What is the width of the proof mass? What is the thickness of the Au layer on proof mass?

**Question 2-2:** **(5%)** What are the spring constant and damping coefficient of the proof mass? What are the equivalent spring constant and referent frequency around tunneling operation position (consider softening spring effect)?

**<u>Question 2-3:</u> (20%)**Download laser vibrometer measurement data -[Xtun.mat](http://mx.nthu.edu.tw/~chhsliu/MEMS/Xtun.mat) ([http://mx.nthu.edu.tw/~chhsliu/MEMS/Xtun.mat](http://mx.nthu.edu.tw/~chhsliu/MEMS/Xtun.mat)) and [Vtip.mat](http://mx.nthu.edu.tw/~chhsliu/MEMS/Vtip.mat) (http://mx.nthu.edu.tw/~chhsliu/MEMS/Vtip.mat).

These data show the tip voltage corresponding to individual tunneling gap. The data sampling rate is 10000Hz. The proof mass is oscillated at 200 Hz during measurement experiment using Laser Vibrometer. The Vtip also collects some noise.

Based on these measurement data, find the values of $I_o$ and $\Phi$.

(where $I_t = I_o \times \exp(-a_I \sqrt{\Phi} x)$ )

**<u>Question 2-4:</u> (70%)**Develop a simulink model to simulate this Micro-ElectroMechanical System. (nonlinear model)

(a) Submit your simulink file.

(b) Plot $V_{pl}$ and $V_{deflectv}$ vs. time for 0.1 μg external acceleration at 50 Hz.

(c) Plot $V_{pl}$ and $V_{deflectv}$ vs. time for 0.1 μg external acceleration at 500 Hz.

(d) Plot $V_{pl}$ and $V_{deflectv}$ vs. time for 0.1g external acceleration at 50 Hz.

(e) Plot $V_{pl}$ and $V_{deflectv}$ vs. time for 0.1 g external acceleration at 500 Hz.