DAMPING AND QUALITY FACTOR OPTIMIZATION IN MEMS MICRORESONATORS

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1. INTRODUCTION

Micro-Electro-Mechanical-Systems (MEMS) resonators are used in many applications ranging from bio-medical to space exploration [1-3]. In this regard, boundary conditioning is a way of modeling the integrated characteristics of material, geometry, boundary support, and operating conditions on the elastic property of suspended microstructures [4, 5]. For microresonators, the effects of damping will affect the dynamic response of suspended microcantilever type devices, where damping in general may be due to structural and or squeeze film effects. An important issue involved in these developments is to characterize the interaction of the resonating structure with the thin gas layer between the structure and its supporting substrate [6].

The performance of many MEMS devices can be improved by tuning the quality factor (Q) of the dynamic system [7]. A high Q can increase the scanning angle of a micromachined optical scanner and the sensitivity of a micromachined microphone [8]. On the other hand, damping can be used to reduce the oscillation of an accelerometer at resonance, and to reduce the settling time of various types of sensors and actuators [9]. In this work, a method using cutouts [10, 11] to tune the dynamic response of the microcantilever and improve the Q of the resonating microdevice is presented.

2. MODEL

The dynamic characteristics of micromachined structures, such as resonant frequency and damping coefficient are usually influenced by air. This squeezed-film effect will introduce an equivalent lumped variable damper and spring model as shown in Figure 1, where the equation of motion for the vibrating structure is given by

$$M\ddot{x} + C\dot{x} + Kx = 0 \qquad (1)$$

where M is the mass, C the damping coefficient and K the stiffness of the system.

The variable nature of the stiffness and damping in this model, as shown in Figure 1, is directly related to the geometry of the cutout. In this regard, the cutout will affect both the stiffness and the damping of the microsystem, and the Q is directly proportional to the reduction in the damping of the microsystem.

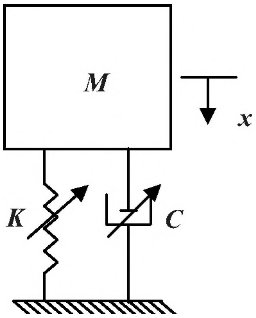

Fig. 1. Lumped mass model of a variable spring-damper resonating microstructure.

Two damped microcantilever models are investigated experimentally in this work. In this first model as shown in Figure 2, the microcantilever cutouts are of equal size for three different microcantilever lengths, while in the second model as shown in Figure 3, the microcantilever length is constant and the slot length is varied. A microscope image of these two cutout models applied to atomic force microscope (AFM) microcantilevers is shown in Figure 4.

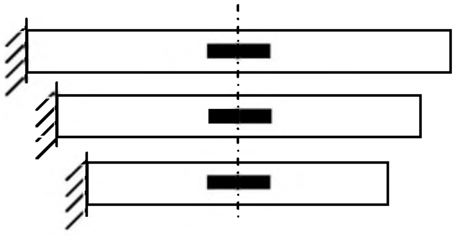

Fig. 2. Top view of three microcantilevers of various lengths with equal cutouts.

The experimental results were obtained by using a non-contact optical test method in which the natural frequencies of the resonating microcantilevers were obtained [12]. A piezo-stack was used for the base excitation in which a swept sinusoidal frequency approach was used. The experimental resonance responses obtained are presented in Figure 5.

3. DISCUSSION

The resonance responses obtained show that the damping can be reduced significantly by the inclusion of a cutout in the microcantilever. The sharpness of the esonance may also be affected by the geometry of the utout. In this regard, cutouts may be used to tune the requency response of a given microcantilever, and also to educe the squeeze film damping in the microsystem.

Fig. 3. Top view of three microcantilevers of the same lengths with various cutouts.

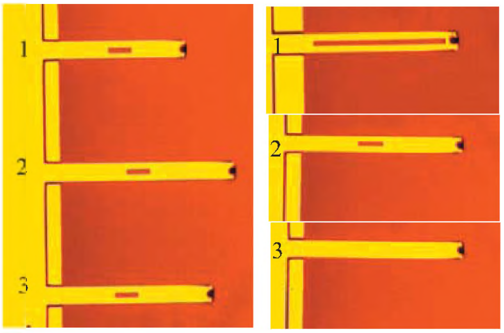

Fig. 4. Left: Microscope image of top view of three AFM microcantilevers of various lengths with equal cutouts. Right: Top view of three AFM microcantilevers of the same lengths with various cutouts.

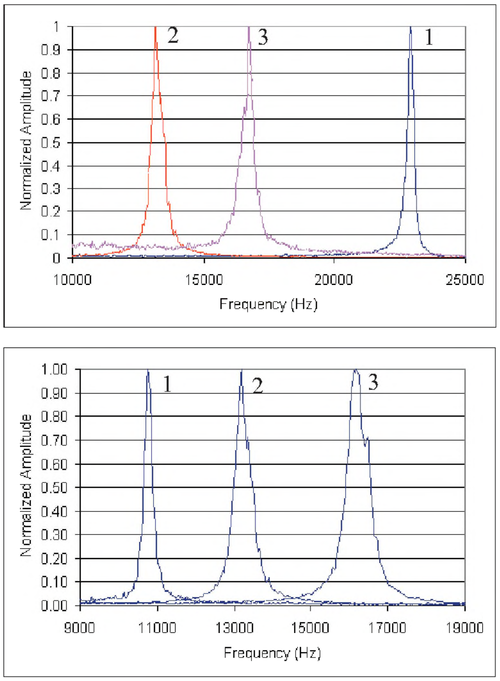

Fig. 5 Top: Frequency responses of three AFM microcantilevers as shown in Fig. 4 (left). Bottom: Frequency responses of three AFM microcantilevers as shown in Fig. 4 (right).

4. CONCLUSION

An experimental investigation into the damping and Q, of resonating AFM microcantilevers has been presented. It was shown that the resonance response and Q can be favourably tuned with the choice of appropriate cutout geometry, where the increase in Q is directly related to the reduction in damping of the microsystem.

REFERENCES

1. Raiteri, R., Grattarola, M., Butt, H.J., Skladal, P. (2001) "Micromechanical cantilever-based biosensors", *Sensors and Actuators: B*, 79, 115-126

2. Riesenberg, R., Nitzsche, G., Wuttig, A., Harnisch, B. (2001) "Micro spectrometer and MEMS for space", 6th ISU Annual International Symposium, Smaller Satellites: Bigger Business, Strasbourg, France, May 21-23

3. Su, M., Li, S., Dravid, V.P. (2003) "Microcantilever resonance-based DNA detection with nanoparticle probes", *Biochemical and Biophysical Research Communications*, 304, 98-100

4. Rinaldi, G., Packirisamy, M., Stiharu, I. (2005) "Multiparameter synthesis of microsystems", Proceedings of SPIE, International Conference on Photonic Devices, Toronto, Ontario, Canada September 12-14

5. Packirisamy, M., Bhat, R.B., Stiharu, I. (1999) "Boundary conditioning technique for structural tuning", *Journal of Sound and Vibration*, 220, 847-859

6. Zhang, C., Xu, G., Jiang, Q. (2004), "Characterization of the squeeze film damping effect on the quality factor of a microbeam resonator", *Journal of Micromechanics and Microengineering*, 14, 1302-1306

7. Cheng, C.-C., Fang, W. (2005) "Tuning the quality factor of bulk micromachined structures using squeezed-film damping", *Microsystem Technologies*, 11, 104–110

8. Lin, H.-Y., Fang, W. (2000) ''Torsional mirror with an electrostatically driven lever-mechanism'' the IEEE Optical MEMS 2000, Kauai, Hawaii, August, 113–114

9. Greywall, D.S., Busch, P.A., Walker, J.A. (1999) ''Phenomenological model for gas-damping of micro mechanical structures'', *Sensors and Actuators: A*, 72, 49–70

10. Rinaldi, G., Packirisamy, M. and Stiharu, I. (2007) "Dynamic analysis of slotted MEMS cantilevers", *International Journal of COMADEM*, 10, 13-19

11. Rinaldi, G., Packirisamy, M. and Stiharu, I. (2006) "Tuning the dynamic behaviour of cantilever MEMS based sensors and actuators", *Sensor Review*, 27, 142-150

12. Rinaldi, G., Packirisamy, M. and Stiharu, I. (2006) "Dynamic testing of micromechanical structures under thermo-electro-mechanical influences", *Measurement*, 40, 563-574