Chapter 5

Conclusions

As mentioned in Chapter 1, the success in MEMS technology largely depends on the understanding of materials. For MEMS actuators, especially for active materials, the desired characterization system for obtaining mechanical properties requires load control feature and the capability to perform dynamic tests. However, there is no such method among the currently available tools for mechanical characterization.

A new technique for the mechanical characterization of released thin films under concentrated load has been developed. This technique can be used to apply load in the μN - mN range by either load control or displacement control. The displacement can be measured to high accuracy, within 0.1 μm. The capability and reliability of this new technique has been demonstrated by studying Si_3N_4 free-standing membranes. The elastic modulus and residual stress of Si_3N_4 free standing thin film are around 250 GPa and 400 MPa, respectively. These values are in close agreement with values obtained using a different technique as well as those found in the literature. The significance of residual stress in design and performance of MEMS devices is discussed.

Another type of load control system for thin film characterization, the pressure bulge test technique, has been adapted to be studied with *in-situ* diagnostics. The comprehensive developments in both the theoretical analysis and experimental techniques make bulge test a reliable method for mechanical characterization of functional thin films and thin film structures. The compact design makes it possible to be fitted into an X-ray diffractometer (XRD) and an optical microscope to observe the microstructural change at the same time as the mechanical characterization. The capability and reliability of the experimental setup were illustrated by studying free-standing silicon-nitride thin films which were tested to obtain the Young's modulus and residual stress. Preliminary results of PBT/Si_3N_4 thin film structure are also reported.

By utilizing the pressure bulge method, the Young's modulus of a barium titanate single crystal thick film (~100 μm) fabricated by the wafer bonding method was characterized. Direct evidence of 90^o domain switching was obtained from the *in-situ* XRD results of the intensity change in both (002) and (200) orientations. Changes in domain patterns were observed by using the polarized light microscopy. At 27.2 kPa pressure, the stress in the center of the film was estimated to be 15.3 MPa in tension and more than 18% of the "c" domains had switched into "a" domains. Quantitative relations between the stress in the thick film and the microstructural change are also reported.

5.1 Suggestions for future work

Starting from current work, there are quite a few interesting areas to continue. The future work will help to understand active materials as well as passive materials. It is described as continuing electro-thermal-mechanical characterization, adding additional features to the apparatus, and studying alternative materials.

5.1.1 Electro-mechanical characterization

The ultimate goal of the Caltech ferroelctric group is to build thin film MEMS actuators with large deformation similar in performance to that of the bulk crystal actuator. This can be accomplished by using current experimental setup together with Sawyer-Tower circuit. As in the bulk crystal case, Sawyer-Tower circuit can provide dynamic electric field excitation and at the same time obtain the polarization data during electromechanical loading. The components of the circuit should be carefully chosen considering the small dimensions of the thin film specimen. The amplitude of the external electric field should also to be chosen considering the small size of the sample in all dimensions. The experimental study should include studying the overall mechanical behavior of the device, microstructural observation by methods such as X-ray diffraction, polarized light microscopy, or micro-Raman studies, and the relation between these two. The degradation or fatigue phenomena would also be interest.

5.1.2 Alternative materials

The current setup can also be used to characterize complex thin film structures or advanced functional thin film materials. For example, shape memory alloys are mechanically active materials. They may generate large deformation due to phase change. The mechanical characterization will help in understanding the behavior of thin films and increase the reliability of devices made from such materials. Interesting mechanical behavior with hysteresis loops are expected during mechanical loading and unloading. The dependence of the mechanical behavior on the loading parameters such as the frequency should also be investigated.

5.1.3 Adding additional features to the apparatus

The current setup with load control feature utilizes the manually controlled permanent magnet to apply load. If the load can be controlled by computer, many interesting studies can be done and more material properties can be obtained, for either active or passive materials [1].

Two possible methods can be used to make the loading system controlled by computer. One of them is to attach the adjustable upper magnet to a micro-actuator, which is computer controlled, instead of the manually controlled micrometer of current setup. In this case, the position of upper magnet controls the total load on the specimen. The other method is to replace the upper permanent magnet with an electro magnet formed by a solenoid. Controlling the current flowing through the solenoid, by a function generator (and voltage amplifier, if needed), the magnetic field will be changed. As a result, the force on the specimen can be changed. After calibration, the loading, which can be recorded by digital oscilloscope, can be related directly to the voltage signal from the function generator. This method is convenient and economic, because the input signal can be arbitrary and the components including the solenoid are inexpensive.

Using the automatically controlled mechanical loading arrangement, much interesting work can be performed to explore thin film materials and structures. The material properties extracted from those experiments include: Young's modulus by current load-deflection method of various sample geometry shapes—membranes, bridges, cantilevers; ultimate strength by pushing the samples to failure, and its rate dependence; life of devices and it's dependence on stress by fatigue testing.

5.2 References

1. Zhang, R., Shilo, D., Ravichandran, G., Bhattacharya, K., "Method and apparatus for measuring the mechanical response of micro-electro-mechanical systems", *US Patent pending*, submitted Dec 13, 2004.