Development of a Mechanical Characterization Technique for Micro- and Nanoscale Polymer Thin-films

Yun Young Kim[1]

[1]Division of Mechanical, Automotive, and Robot Component Engineering, Dong-eui University, Busan, 47340, Republic of Korea

ykim@deu.ac.kr

ABSTRACT

A measurement technique for the mechanical characterization of micro- and nanoscale polymer thin-films was introduced in the present study. An experimental setup was established using an ultrasonic pulser that actuates a microcantilever so that material properties such as the Young's modulus and shear modulus can be determined by detecting the resonant frequency shift upon coating of a thin-film to be evaluated using a laser interferometer. The present research proposes an evaluation method for the robust design of organic electronics and energy devices.

1. INTRODUCTION

Polymer thin-films are used in the next-generation engineering applications such as flexible electronics, wearable devices, organic photovoltaics, and so on. For the robust design of such products, it is important to know the material properties and understand its degradation behavior. The material characteristics in the micro- and nanoscopic scale, however, often differ from those of the macroscopic counterpart due to the increase of the surface area-to-volume ratio that results in the scale effect. Therefore, the development of materials testing methods suitable for the corresponding length scale is required.

Due to the relatively lower Young's modulus of polymer, unless it exists in the form of a composite material, compared to other materials such as metal and ceramic, conventional measurement techniques such as the microtensile testing (Kim *et al*., 2005) and nanoindentation testing (Oliver & Pharr, 1992) may not work effectively. Also, *in situ* testing methods are often preferred to contact-based destructive techniques to reduce the manufacturing lead time.

Therefore, a nondestructive microcantilever testing method is developed in the present study so that mechanical properties of nanoscale thin-films can be determined.

2. EXPERIMENTAL SETUP

In the microcantilever testing, a micromachined cantilever structure, or a *microcantilever*, typically formed on a silicon wafer is used to detect its resonance frequency shift upon coating of a thin-film to be evaluated. Figure 1 shows a schematic representation of the experimental setup. Unlike conventional atomic force microscopy-based approaches based on a position-sensitive detector, a laser interferometer was used for the detection of the vibration signal from the microcantilever surface, and an ultrasonic pulser for the excitation of free vibration of the microcantilever in the megahertz frequency range. Feedback electronics composed of a piezo-driver and proportional-integral-derivative (PID) controller may be employed to filter low-frequency noises. In this way, much faster actuation and detection are possible to enhance the mass sensitivity of the setup down to fg/Hz.

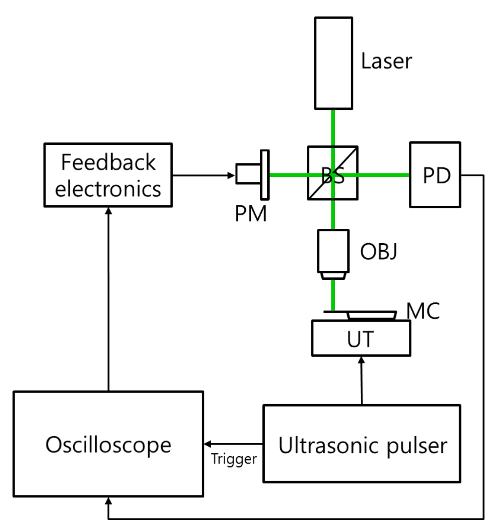

Figure 1. A schematic of the microresonance testing apparatus. BS: beam splitter; MC: microcantilever; OBJ: objective lens; PD: photodetector, PM: piezo-actuated mirror; UT: ultrasonic transducer.

3. RESULTS AND DISCUSSION

Figure 2 shows a typical vibration signal obtained from the experiment. In this case, a quartz cantilever of which size is 20 µm (length) × 10 µm (width) × 700 nm (thickness) with 30-nm thick gold coatings on both sides for optical reflection. The frequency response of the microcantilever can be identified through the fast Fourier transform of the time-domain waveform, and the resonant frequency is 1.317 MHz in the present example. The resonant frequency is proportional to the square root of the flexural rigidity, or the product of Young's modulus and area moment of inertia as follows (Thomson, 2003):

$$f_n = \frac{k_n L}{2\pi}\sqrt{\frac{EI}{\rho A}}\frac{t}{L^2} \tag{1}$$

where k_nL is the coefficient for the nth vibration mode (for example, k_1L = 1.8751, k_2L = 4.6941, and so on). E is the Young's modulus, I is the area moment of inertia, ρ is the density. Also, A, t, and L are the cross-sectional area, thickness, and length of the microcantilever, respectively. Therefore, the addition polymeric layer will shift the resonant frequency, and the material property can be obtained through theoretical estimation or numerical analysis using conventional finite element software. Currently a study is in progress to characterize polymer thin-films such as poly(methyl methacrylate) for the nanocomposite matrix and poly(3,4-ethylenedioxythiophene) polystyrene sulfonate for organic solar-cells using the technique.

4. CONCLUSION

A measurement technique for the mechanical properties of micro- and nanoscale polymer thin-film was introduced in the present study. An advanced microcantilever testing setup was established, and the actuation and detection of the vibration signal of a microcantilever were demonstrated. The present research proposes an enhanced evaluation technique for the robust design of polymer-based devices.

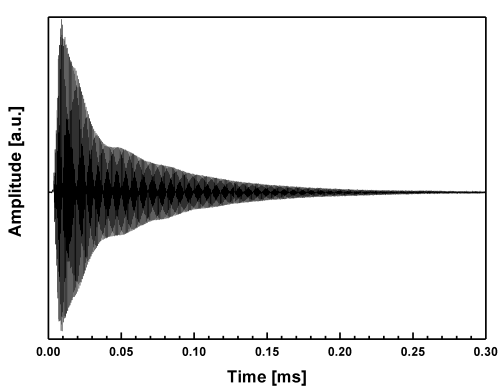

Figure 2. A time-domain waveform of a freely-vibrating microcantilever.

ACKNOWLEDGEMENT

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Science, ICT & Future Planning (No. 2015R1C1A1A01053635).

REFERENCES

Oliver, W. C. and Pharr, G. M. (1992). *An improved technique for determining hardness and elastic modulus using load and displacement sensing indentation experiments*. Journal of Materials Research, vol. 7, pp. 1564-1583. doi: 10.1557/JMR.1992.1564

Kim, S. –S., Lee, H. –J., Lee, H. –W., Lee, N. –K., Han, C. –S., and Hwang, J. –H. (2005). *Development and verification of PZT actuating micro tensile tester for optically functional materials*. International Journal of Control, Automation, and Systems. vol. 3, pp. 477-485.

Thomson, W. T. (2003). *Theory of vibration with applications*, 4th ed. New York, NY: Taylor & Frances

BIOGRAPHIES

Yun Young Kim has received his B.S. and M.S. degrees in Mechanical Engineering at Yonsei University, Seoul, Republic of Korea, and Ph.D. degree in Mechanical Engineering at Northwestern University, Evanston, USA. He is currently an assistant professor in the Division of Mechanical, Automotive, and Robot Component Engineering at Dong-eui University. His primary research interests are in the thin-film mechanics and laser ultrasonic characterization of nanoscale materials. He is currently a member of the Korean Society of Mechanical Engineers as well as the Korean Society for Nondestructive Testing.