Experimental study of energy dissipation in nano-layered thin films

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With magnetron sputtering techniques, well-defined solid thin films consisting of layers with thicknesses of a few nanometers up to several hundred nanometers can be manufactured in high quality. The mechanical properties of the films are of scientific interest and importance for engineering applications. Among them, energy dissipation and fatigue properties of the films are less well studied.

We develop a novel experimental apparatus, referred to as the resonant frequency device, and establish methodology to measure both the energy dissipation and fatigue properties of self-supported thin solid films. Arranging thin-film strips of our specimens into the mechanical setting of a cantilever beam and using state-of-the-art piezo actuators to generate oscillation at the clamp of the cantilever, we create a system suitable for studying the material properties of the cantilever, such as Young's modulus, fatigue S-N curves, and loss tangent in the context of linear viscoelasticity. The system can be regarded as the mechanical problem of viscoelastic elastica [1] with distributed loading. Deformation of the cantilever is our controlled variable in the present study, and measured with fiber-optic probes pointed at the specimen and at the piezo driver. Stress is calculated from relative deformation of the cantilever specimen with respect to the piezo actuator via a photograph of the cantilever under vibration with a curve fitting method. Material damping is measured from both the width of a resonance peak and a free-decay process. A LabView computer program is developed for the fatigue tests to accurately count number of cycles applied on the specimens, and a feedback mechanism is adopted to maintain displacement during the tests. Here, we present our experimental setup, procedure and theoretical models for material-property extraction. For small displacement, the two-dimensional Euler-Bernoulli beam theory is adopted. With large displacement, the system behaves as the Duffing oscillator due to geometrical nonlinearity. In addition, some experimental observations of the piezo actuators and fiber optics are reported. The method is applied to evaluate the fatigue and energy-dissipation properties of nanolayered copper-niobium composites and significant increase in the fatigue endurance limit compared to the constituent materials in the bulk form is noted. Furthermore, we focus on the establishment of methodology to extract material properties through a vibrational process with the consideration of geometric nonlinearity and the investigation of deformation mechanisms of materials with a geometry in the two-dimensional limit.

References

[1] Love, A.E.H. (1944). *A Treatise on the Mathematical Theory of Elasticity.* Dover Publications, New York.

Keywords: nano-layered thin films, Duffing oscillator; geometrical nonlinearity