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A resonant method for determining mechanical properties of Si_3N_4 and SiO_2 thin films

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Abstract

This study investigates the measurement of Poisson's ratio and Young's modulus of silicon dioxide (SiO_2) and silicon nitride (Si_3N_4) thin films using a resonant method. Two thin films, which are SiO_2 and Si_3N_4, are fabricated as the specimens of microcantilever beams and plates using the bulk micromachining. The resonant frequency of the cantilever beams and plates is measured using a laser interferometer. The Young's modulus of thin films can be calculated from the resonant frequency of the cantilever beams, and the Poisson's ratio of thin films is determined by the frequency of the cantilever plates. Experimental results show that the Poisson's ratios of SiO_2 and Si_3N_4 are 0.16 and 0.26, respectively, and the Young's moduli of SiO_2 and Si_3N_4 are, respectively, 55.6 GPa and 131.6 GPa.

Keywords: Young's modulus; Poisson's ratio; Thin films

1. Introduction

The Young's modulus and Poisson's ratio are two important mechanical properties of thin films. The static or dynamic behavior of several micromechanical sensors and microactuators, such as accelerometers [1] and RF micromechanical switches [2], depends on the mechanical properties of thin films. The Young's modulus and Poisson's ratio of thin films depend on the microstructure (grain size, orientation, and density) of the films, which is determined by the specific deposition conditions. The microstructure of thin films changes with the heat cycle, resulting in a change in the mechanical characteristics. It is difficult to evaluate the Young's modulus and Poisson's ratio of thin films using the simulation method according to the deposition conditions of the films. Therefore, the mechanical properties of thin films are always determined by experimental measurement methods [3–6].

In this work, we propose a resonant method, which is based on a PZT vibrator and a laser interferometer, to determine the Poisson's ratio and Young's modulus of thin films. The method has high accuracy owing to the nano-scale resolution of the PZT vibrator and laser interferometer. The PZT vibrator excites the cantilever beams and plates to generate vibration, and the laser interferometer measures the resonant frequency of the cantilever beams and plates. The Young's modulus and Poisson's ratio of thin films can be evaluated according to the resonant frequency of the cantilever beams and plates, respectively.

2. Principle

Two micromachined structures, microcantilever beam and plate, are applied to measure the resonant frequencies and to evaluate the Young's modulus and Poisson's ratio of thin films.

2.1. Evaluating the Young's modulus of thin films

The equation of motion for the free vibration of a uniform beam can be expressed as [7]

$$EI\frac{\partial^4 w}{\partial x^4}(x,t) + \rho A\frac{\partial^2 w}{\partial t^2}(x,t) = 0 \quad (1)$$

where E is the Young's modulus; I is the moment of inertia of the beam cross section; $w(x,t)$ is the transverse displacement of

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the beam; ρ is the mass density of the beam and A is the cross-sectional area of the beam. The first natural frequency of cantilever beam can be expressed as [7]

$$\omega = (1.875)^2 \sqrt{\frac{EI}{\rho A L^4}} \tag{2}$$

where L is the length of the cantilever beam. According to Eq. (2), we know that the Young's modulus, E, depends on the first resonant frequency, ω. The beams are made from thin films. The parameters of the beams, I, A, L and ρ, are also given. Therefore, the Young's modulus of thin films can be evaluated by Eq. (2) if the first resonant frequency of the beams is measured.

2.2. Evaluating the Poisson's ratio of thin films

The classical differential equation of motion for the free vibration of a rectangular plate is given by [8]

$$D\nabla^4 w + \rho \frac{\partial^2 w}{\partial t^2} = 0 \tag{3}$$

where w is the transverse deflection of the plate; ρ is the mass density per unit area of the plate; ∇^4 is the biharmonic differential operator; t is the time and D is the flexural rigidity of the plate. Rossi and Laura [9] obtained the natural frequencies of the cantilever plate using the finite element method. The first natural frequency of the cantilever plate, ω_1, for $a/b=2$ can be written as [9]

$$\omega_1 = \frac{\Omega_1}{a^2} \sqrt{\frac{Eh^2}{12\rho(1-\nu^2)}} \tag{4}$$

where Ω_1 represents the first natural frequency coefficients of the cantilever plate; E is the Young's modulus; h is the thickness of the plate; ν is the Poisson's ratio of the plate; ρ is the mass density per unit area of the plate; a and b are the length and width of the plate, respectively. According to Eq. (4), we know that the Poisson's ratio, ν, depends on the first resonant frequency, ω_1. The plates are made from thin films. The parameters of the plates, E, h, a, Ω_1 and ρ, are given. Therefore, the Poisson ratio of thin films can be evaluated by Eq. (4) if the first resonant frequency of the plates is measured.

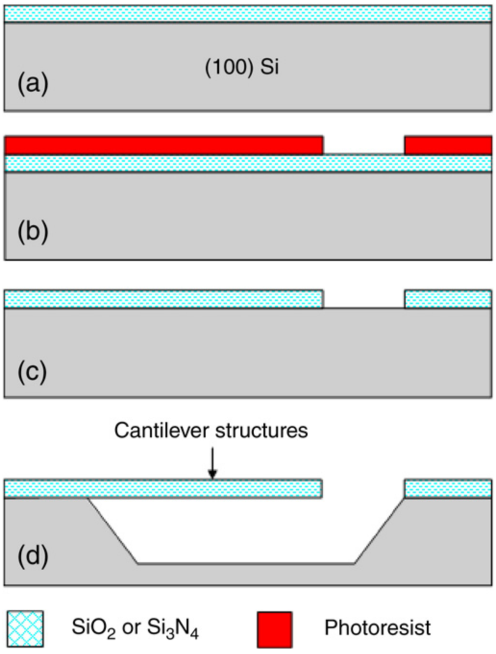

Fig. 1. Process flow of microcantilever beams and plates; (a) depositing LPCVD SiO_2 or Si_3N_4 layer, (b) spinning the photoresist, (c) patterning the LPCVD SiO_2 or Si_3N_4 layer and (d) etching the silicon substrate by KOH.

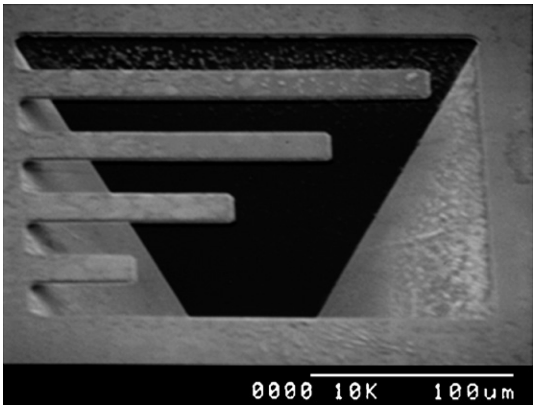

Fig. 2. SEM photograph of SiO_2 cantilever beams.

3. Fabrication of specimens

Four kinds of specimens are fabricated — SiO_2 cantilever beam, Si_3N_4 cantilever beam, SiO_2 cantilever plates and Si_3N_4 cantilever plates. Fig. 1 depicts the process flow of the chips. First, low-pressure chemical vapor deposition (LPCVD) is used to deposit SiO_2 or Si_3N_4 films on an orientation (100) silicon substrate, as shown in Fig. 1(a). Second, the photoresist (AZ-5214) is spun on the SiO_2 or Si_3N_4 films, and patterned by photolithography. The shapes of the cantilever beams and plates are formed in the photoresist, as illustrated in Fig. 1(b). Third, CF_4/O_2 reactive ion etching (RIE) is use to etch the SiO_2 or Si_3N_4 films. The cantilever beams and plates are patterned in the SiO_2 or Si_3N_4 films, and then the photoresist is striped, as shown in Fig. 1(c). Finally, the anisotopic etchant KOH heated to temperature of 80 °C is utilized to etch the silicon substrate, and released the suspended microstructures of the cantilever plates and beams, as illustrated in Fig. 1(d). Fig. 2 displays the SEM (Scanning electron micrograph) photograph of the SiO_2 cantilever beams after the process.