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All-optical actuation of amorphous chalcogenide-coated cantilevers

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Abstract

An extensive study has been carried out of the optical actuation of amorphous chalcogenide-coated cantilevers, wherein a reversible deflection up and down of such bimorph structures occurs under constant illumination with linearly polarized light, on rotating the polarization axis. The largest, and fastest, optically-induced cantilever displacement occurs for high-intensity actuating light having a photon energy comparable to the bandgap of the amorphous chalcogenide semiconductor.

Keywords: Amorphous semiconductors; Films and coatings; Infrared glasses; Chalcogenides

1. Introduction

Chalcogenide glasses or amorphous thin films exhibit a plethora of interesting opto-electronic phenomena, which are interesting both from an academic point of view and for technological applications [1,2]. These semiconducting materials exhibit, in particular, one very fascinating type of behavior, namely intrinsic photosensitivity leading to optically-induced changes. These changes may be of several different kinds [3,4]. They may be *dynamic* (only present during optical excitation) or *metastable* (remaining after cessation of illumination). Furthermore, they may be *irreversible* or *reversible* (upon appropriate thermal or optical annealing). Finally, the changes may be *scalar* in nature (i.e., independent of the polarization of the inducing light) or *vectoral* (dependent on the polarization, or propagation direction, of the inducing light), leading to optically-modified isotropic or anisotropic behavior, respectively. Perhaps the most intriguing of all these optically-induced phenomena are the vectoral effects, wherein an originally isotropic amorphous material is rendered anisotropic in some of its properties merely by the absorption of (generally linearly) polarized light.

The most commonly studied vectoral effect is photoinduced anisotropy in the optical properties of chalcogenide materials, namely birefringence and dichroism [3,4]. However, some time ago, we discovered a related effect in the *mechanical* behavior of these glasses, namely the opto-mechanical effect (OME) [5], wherein the absorption of linearly-polarized light by an amorphous chalcogenide overlayer on a clamped microcantilever caused a differential, anisotropic change in mechanical strain, resulting in an upward displacement of the cantilever for light polarized parallel to the cantilever, and a downward displacement for perpendicularly-polarized light.

These initial experiments were undertaken using vee-shaped cantilevers made from Si_3N_4, coated with the chalcogenide a-$As_{50}Se_{50}$. In this work, we have also studied the behavior of rectangular cantilevers made from single-crystal Si, coated with thin films of chalcogenides in the system $As_{40}S_xSe_{60-x}$ $(0 < x < 60)$, as a function of illuminating light wavelength and intensity. Some preliminary results have been published elsewhere [6–8].

2. Experimental

Full details of the experimental procedures used in this study are given elsewhere [9]; brief relevant details are given here. Rectangular force-calibration microcantilevers,

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etched from a <1 0 0> single-crystal Si wafer, were obtained from Thermo Microscopes Inc. These had thicknesses of 2.85 μm and widths of 35.2 μm; three cantilevers were attached to each supporting chip, having lengths of 81, 181 and 381 μm, respectively. Thin films of amorphous chalcogenides, having thicknesses ranging from a few hundred nanometres to a few microns, were deposited on the top polished surfaces of the cantilevers by thermal evaporation of bulk glasses having the compositions $As_{40}S_xSe_{60-x}$ $(0 < x < 60)$, as well as $As_{50}Se_{50}$.

A schematic illustration of the measurement set-up is shown in Fig. 1.

Three lasers were used as illumination sources: a 5 W Coherent-Verdi V-5 Nd:YVO_4 laser, used either alone (532 nm) or as a pump for a Coherent 899-01 500 mW dye ring laser (550–620 nm), as well as a 10 mW JDS Uniphase 1135/P He–Ne laser (633 nm). The laser beams were focussed such that the central, approximately constant-intensity part of the Gaussian beam profile illuminated the length of the longest cantilevers. Polarization control of the illuminating beams was achieved by means of a pair of Newport calcite Glan–Thompson prisms or, for rapid switching between orthogonal directions, a Quantum Technology model 28 electro-optical modulator. Cantilever motion was detected by means of an optical-lever set up, wherein light from a modulated (39 kHz) IR laser diode (typically 3 mW, 655 nm), focussed onto the under-side tip of a cantilever, was reflected onto a position-sensitive detector (UDT Sensors SPOT-0DMI quadruple photodiode) whose output was fed into a Stanford Research Systems SR830 lock-in amplifier. For most purposes, cantilever displacements were simply recorded in terms of detector output (relative millivolts or arbitrary units, a.u.), but for one particular cantilever configuration (381 μm long, 1 μm thick film of $As_{40}S_{35}Se_{25}$), a calibration curve was established between actual displacement (measured by rotating the cantilever chip in an accurate goniometer in order to compensate for any optically-induced deflection) and photodiode output. All measurements were performed at room temperature, in air. The experimental protocol was adopted wherein the *initial* polarization of the actuating light was always perpendicular (⊥) to the cantilever axis in any series of experiments. Least-squares fits to the kinetic data were performed using the stretched-exponential function as the fitting function in order to extract the relevant parameters, namely the stretching coefficient (β) and the characteristic time (τ). The correlation coefficients of the fits were typically 99.9%.

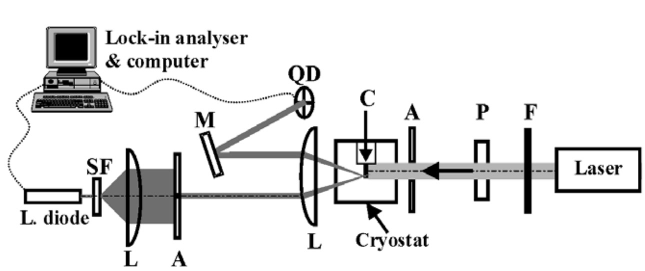

Fig. 1. A schematic illustration of the experimental set-up used to measure the opto-mechanical effect: F is a neutral-density filter, P is a $\lambda/2$ waveplate or two Glan–Thompson prisms, A is an iris attenuator, L is a lens, SF is a spatial filter, M is a mirror, QD is a quadruple diode and C is the cantilever.

3. Results

3.1. General

Illumination of a chalcogenide film – Si cantilever bimorph causes a mechanical deflection for three reasons: (i) a thermal (bimetallic-strip) effect due to different coefficients of thermal expansion; (ii) a scalar photo-expansion of the chalcogenide and (iii) a vectoral photo-expansion/contraction of the chalcogenide. The first effect is by far the most rapid, and when effects (i) and (ii) have stabilized under constant-illumination conditions (see Fig. 2(a)), then the vectoral effect (iii), of interest here, can be explored (see

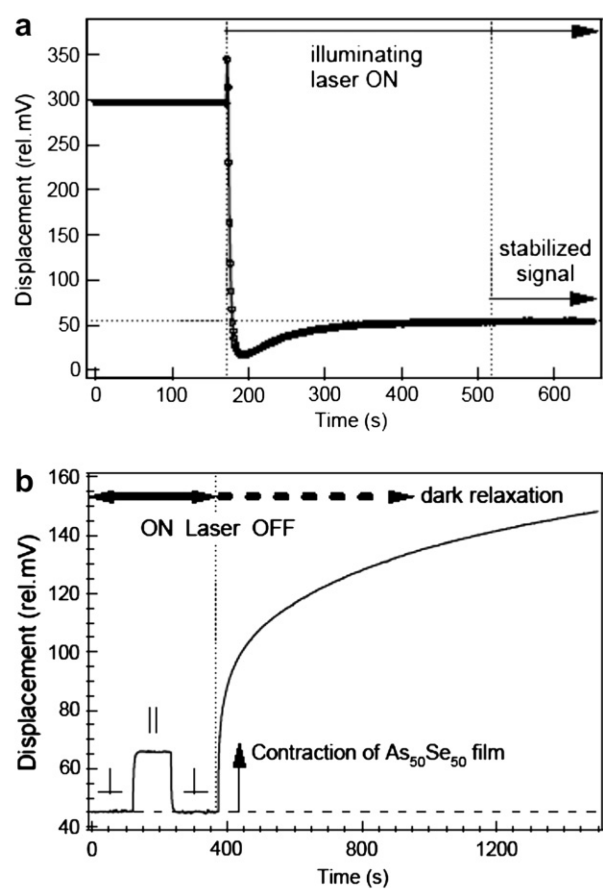

Fig. 2. Initial and final behavior of cantilever displacement on illumination: (a) initial effect, where thermal, scalar and vectoral optical effects occur simultaneously in $As_{40}S_{20}Se_{40}$ and (b) illustration of the vectoral opto-mechanical effect for $As_{50}Se_{50}$, followed by the dark relaxation of the (scalar) photo-expansion on cessation of illumination. The initial stabilized position of the cantilever, after the initial transient effects have disappeared, is at 45 a.u. for ⊥ illumination. The lines through the data points are guides to the eye.