OPTOMECHANICAL SWITCHING USING INTERCALATED GRAPHITE

Michael S. Salib, Athos Petrou and D.D.L. Chung

Center for Electronic and Electro-Optic Materials
State University of New York at Buffalo
Buffalo, NY 14260-4400

INTRODUCTION

Smart materials comprise materials that have one or both of the following functions -- sensing and actuation. Sensing refers to the sensing of strain or stress, while actuation refers to providing strain or stress. The signal sensed and the signal that actuates can be electrical, magnetic or optical. For example, the piezoelectric effect, the piezoresistive effect, the electrostrictive effect and the electrorheological effect involve an electrical signal; the magnetostrictive and magnetorheological effects involve a magnetic signal; the optical fibers and the photoelastic effect involve an optical signal.

A new effect is the electromechanical effect in intercalated graphite. This effect involves the reversible expansion of intercalated graphite by up to 4500% along the c-axis upon passing an electric current along the c-axis; the equivalent stress generated is up to 3 MPa [1]. In other words, intercalated graphite is an actuator that responds to an electrical signal, which heats the sample, thereby causing reversible exfoliation expansion, at 100°C in the case of graphite intercalated with bromine [2]. The heating may be provided by an optical beam instead. The use of infrared and laser heating methods had been previously used for irreversible exfoliation [3], but not reversible exfoliation. Reversibility is essential for switching. The optomechanical effect is expected to be practically useful for adaptive optics. In this work, the optomechanical switching was observed and characterised.

EXPERIMENTAL METHOD

The sample used was a graphite-bromine residue compound based on highly-oriented pyrolytic graphite (HOPG), of size 5.1 x 4.1 x 1.0 mm, and containing 0.4 mole % Br_2. Intercalation was carried out by exposure to bromine vapor in air at room temperature to attain stage 2, followed by intercalate desorption below 100°C. A few cycles of reversible exfoliation were carried out on a hot plate prior to the optomechanical measurement in order to avoid any intercalate desorption during the optomechanical measurement.

The optomechanical effect was observed by directing laser radiation (unfocused, 1 mm diameter) onto the sample (5.1 x 4.1 mm) and measuring the strain optically during laser irradiation switching. The setup consisted of a Michelson interferometer in which the moveable lightweight mirror M1 was mounted on the sample under study. The second mirror (M2) was stationary. The sample surface perpendicular to the c-axis was illuminated from the back by a strong argon-ion laser beam (wavelength = 5145 Å at a power of 400 mW), which induced a change δz in the near-surface sample thickness along the c-axis. Mirror M1 traveled by the same amount toward the beam splitter and caused the movement of $2\delta z/\lambda$ interference fringes on the photo-diode detector, which were recorded by the counter. A weak (0.5 mW) He-Ne laser (λ = 6328 Å) was used as a probe beam for the observation of the interference fringes so as to measure the amount of expansion or contraction. The resolution in δz was 500 Å.

RESULTS AND DISCUSSION

The whole sample expanded uniformly and reversibly along the c-axis during laser irradiation, such that it took 15 s to expand by 3λ and 45 s to expand by 4λ (the total expansion). Upon removal of the laser irradiation, the contraction along the c-axis was also uniform, such that it took 15 s to contract by 3λ and 45 s to contract by 4λ (the total contraction). Even though the laser beam size was much smaller than the sample size, the whole sample expanded. This is due to the high in-plane thermal conductivity. The fractional expansion was only 0.25%, if the whole sample thickness was considered. This implies that only the limited depth of the sample near the irradiated surface expanded. Upon increasing the argon laser power (from 0 to 5 W), no change of the fringe shape was observed. This means that the sample underwent negligible dimensional change in the in-plane directions during the expansion along the c-axis. In spite of the small amount of expansion and the long rise time and fall time, the reversibility and uniformity of the expansion promise use of the optomechanical effect for adaptive optics.

The use of a sample with a higher intercalate concentration (2 mole % Br_2, not a residue compound) gave similar behavior, except that the expansion was larger and slower (5λ in 60 s), less uniform and less reversible. Thus, a low intercalate concentration is more desirable.

The observed optomechanical effect differs from the related electromechanical effect in the same material [1] in that the expansion is much larger in the latter and the fall time and rise time are much shorter in the latter. The large expansion in the electromechanical effect is because the whole thickness of the sample expanded. The short rise time in the electromechanical effect is because direct Joule heating rather than optical heating was involved. In spite of the low expansion and long rise and fall times in optomechanical switching, optomechanical switching is attractive in its requiring no electrical contacts, in contrast to this requirement in electromechanical switching. The absence of electrical contacts makes optomechanical switching easier to implement than electromechanical switching.

CONCLUSION

Optomechanical switching was observed in intercalated graphite. For a residue compound, the c-axis expansion was uniform across the whole plane perpendicular to the c-axis, even though the laser beam was smaller than this plane. The expansion was reversible. Only the limited depth of the sample near the irradiated surface expanded. The total c-axis expansion was 2.5 μm. The first 3/4 of the total expansion took 15 s; the total expansion took 45 s. Similarly, upon removal of the laser irradiation, the first 3/4 of the total contraction took 15 s and the total expansion (2.5 μm) took 45 s.

REFERENCES

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