Optomechanical actuation using intercalated graphite

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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, piezoelectric, piezoresistive, electrostrictive and electrorheological effects involve an electrical signal; magnetostrictive and magnetorheological effects involve a magnetic signal; while optical fibers and the photoelastic effect involve an optical signal.

A relatively new effect is the electromechanical effect in intercalated graphite. This effect involves the reversible expansion of intercalated graphite by up to 4500% parallel to the c-axis upon passing an electric current in the same direction; the equivalent stress generated is up to 3 MPa [1,2]. 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 [3]. The heating may be provided by an optical beam instead. The use of

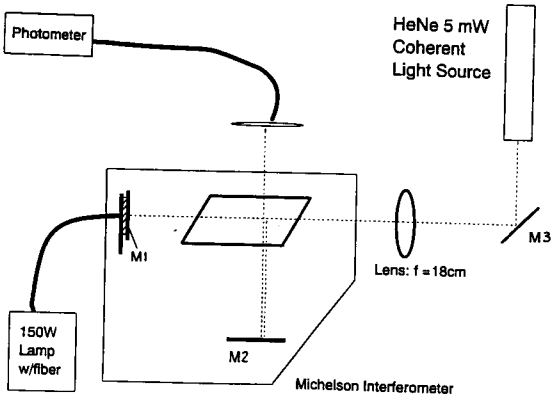

Fig. 1. Set-up for optomechanical testing.

infrared and laser heating methods had been previously used for irreversible exfoliation [4], but not for reversible exfoliation. Reversibility is essential for switching. The optomechanical effect is expected to be practically useful for adaptive optics, optically controlled movement and smart thermal/electrical contacts. In this work, the optomechanical switching was observed and characterised.

The sample used was a graphite-bromine residue compound based on highly-oriented pyrolytic graphite (HOPG), of size 4.2 x 3.3 x 1.0 mm, and containing 1.9 mol% 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. The optomechanical effect was observed by directing unfocused 400-500 mW white light (150 W tungsten-halogen lamp, via an optical fiber bundle of diameter 3 mm) onto the sample (4.2 x 3.3 mm) and measuring the strain optically during irradiation switching. The set-up (Fig. 1) consisted of a Michelson interferometer in which the moveable lightweight mirror M1 was mounted on the sample being studied. The second mirror (M2) was stationary. The sample surface perpendicular to the c-axis was illuminated from the back by the white light, 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 (5 mW) He-Ne laser (λ = 6328 A) 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 500Å.

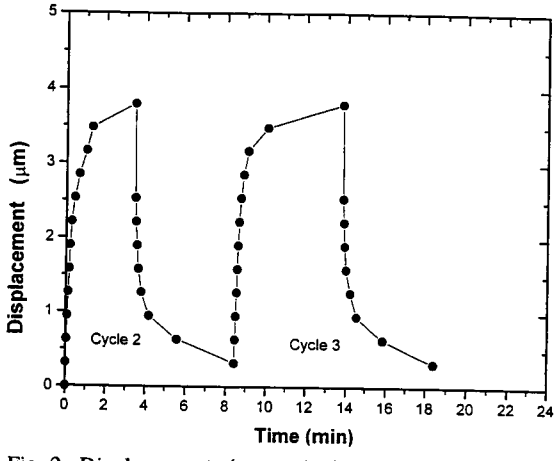

Fig. 2. Displacement (expansion) versus time during cycles 2 and 3 of optomechanical switching.

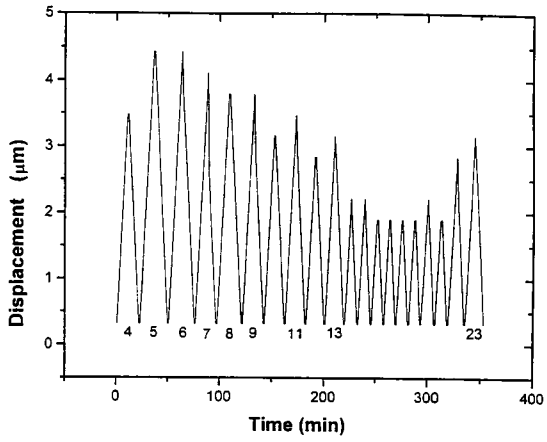

Fig. 3. Displacement (expansion) versus time during cycles 4 - 23 of optomechanical switching.

The whole sample expanded uniformly and reversibly along the c-axis during light irradiation, as shown in Fig. 2 for cycles 2 and 3 and in Fig. 3 for cycles 4 - 23. Upon removal of the light irradiation, the contraction along the c-axis was also uniform. Even though the light beam size was smaller than the sample size, the whole sample expanded. This is due to the high in-plane thermal conductivity. Only the limited depth of the sample near the irradiated surface expanded as the expansion was less than 5 μm. The expansion varied from cycle to cycle, as shown in Fig. 3, probably because of the slight variation of the depth of optical heating from cycle to cycle. The rise/fall time was 15 s for the main (initial) parts of the rise and fall. No correlation was found between the expansion and the intercalate concentration.

Irradiation using an argon-ion laser beam (wavelength = 5145 Å at a power of 400 mW) instead of white light gave results similar to Figs. 2 - 3. Upon increasing the argon laser power (from 0 to 1 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.

The observed optomechanical effect differs from the related electromechanical effect in the same material [1,2] in that the expansion is much larger, and the fall and rise times 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, the phenomenon is attractive in its requiring no electrical contacts, in contrast to this requirement in electromechanical switching. This makes it easier to implement.

In conclusion, optomechanical actuation was achieved reversibly using highly oriented pyrolytic graphite intercalated with bromine (1.9 mol% Br_2). White light from a 150 W tungsten-halogen lamp was used for optomechanical switching. The displacement was ~4 μm and occurred only along the c-axis of the graphite and for the limited depth of the sample near the

irradiated surface. The expansion was uniform across the whole plane perpendicular to the c-axis, even though the switching beam was smaller than this plane. The rise and fall times were ~15 s. The origin of the optomechanical effect is the reversible exfoliation of the near surface region of the intercalated graphite.

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