Communication

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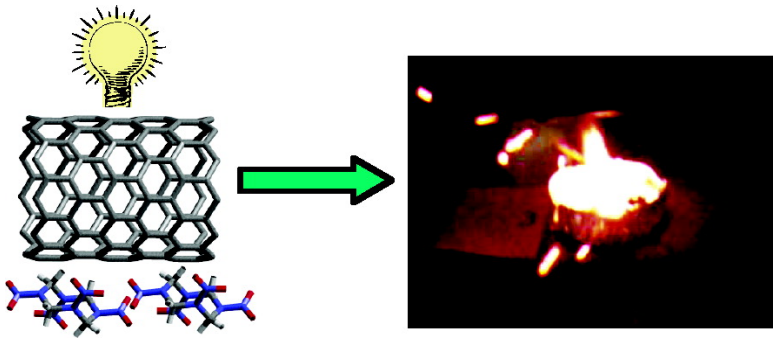

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Flash Ignition and Initiation of Explosives−Nanotubes Mixture

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The recent astounding discoveries of ignition in single-walled carbon nanotubes (SWNTs) after exposure to an ordinary photographic flash,[1] other formulations of carbons containing noble metals,[2] and polyaniline nanofibers[3] prompted us to explore a possible further investigation of explosive materials. Optical ignition and initiation of energetic materials has the following important practical benefits: (1) the optical signal is immune to electromagnetic interference and varying conditions of pressure and temperature, and (2) the pulse delivery is not dependent on materials that might degrade over time. Here, we report that an ignition and an initiation process, further leading to actual detonation, does occur for energetic materials in lax contact with carbon nanotubes that are prone to opto-thermal activity via a conventional flashbulb. Optical ignition and initiation of explosives could thus far only be accomplished through lasers,[4] with specific characteristics of high power, pulse length, wavelength, and a small target area that greatly inhibit their applications. Our results show that, for the first time, optical initiation of energetic materials is possible on a large surface area and using ordinary light power in the milliwatts range. These results have the implication that explosive materials with opto-thermally active SWNT formulations are new ideal candidates for remote optical triggering of safety apparatus, such as the firing of bolts on space shuttle rockets and aircraft exit doors, and for controlled burning of explosives as energy actuators.

Ignition in an explosive target can be achieved by applying a thermal stimulus that causes local burning at a particular site. Initiation is achieved once the local burning accelerates into a violent reaction with the formation of a shock front and the rapid build-up to detonation. Using a common electronic strobe of flash photography (Albinar 120MDT-TZ with 5600 K of color temperature), we flashed several samples with various combinations of the explosive PETN (pentaerythritol tetranitrate) and commercially obtained SWNTs (as produced raw HiPco from Carbon Nanotechnologies, Inc., with at least 29% per weight iron impurity). Ignition and burning proceeded with bright illumination and glow (Figure 1), compared to a control sample of only SWNTs. In air, the average light power output was 17 W/cm^2 with a duration time of 1−2 ms. Large photoacoustic effects were observed in all flashed samples, while samples compacted to higher densities ignited less brilliantly. On the basis of weight measurements, PETN was completely burned in all experiments, while the SWNTs lost about a third of its mass during the burning process.

Efficient heat transfer from the ignited nanotubes to relatively large crystallites of PETN (∼5 μm in diameter, Figure 2) is key to the explosive's ignition. From the observed structural reconstruction of flashed SWNTs, local temperatures were estimated to be in the range of 1500−2000 °C.[1] Several studies also showed that the thermal conductivity of nanotubes is very high.[5−7] These two factors account for the observed rapid ignition and burning of the explosive materials placed on the bottom of SWNTs. At the microscopic level, vast empty regions separate the PETN crystallites and the nanotubes.

Figure 1. Burning of a 10 mg sample of SWNT placed on top of 10 mg of PETN upon irradiation with a common camera flashlight. Samples were placed 3 cm from the light source.

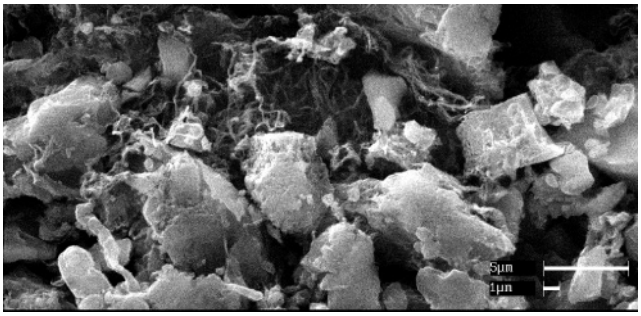

Figure 2. Scanning electron microscopy (SEM) image showing micron-sized PETN grains among SWNTs.

However, the absorbing particles in the nanotubes are the natural hot sites of reactions, the counterparts of local zones of high temperatures known as hot spots, whose growth and interaction is essential for ignition and initiation of explosives.[8]

Next, we investigated whether the deflagration process could actually transition to detonation. It is well-known that transition to detonation in energetic materials is associated with the presence of defects (e.g., voids) in the materials, which serve as local zones of energy deposits whose growth and interaction are the key ingredients for reaching detonation.[4,8] In that vain, we loaded 30 g of K-6, a cyclic dinitrourea explosive,[9] into an 8 in. copper cylinder with 1/2 in. internal diameter and attached it to a 2 in. diameter copper funnel with a 1/8 in. diameter orifice at one end and to a witness plate at the other. Loosely packed SWNTs (0.020 g) were added on top of the K-6. We placed pins that record the arrival time of the shock wave at selected intervals on the cylinder (Figure 3) to measure the speed of the shock wave. A flash bulb (No. 3 bulb manufactured by Sylvania, which provides 110 000 lm·s or 160.6 J of light energy with 3800 K color temperature light) was

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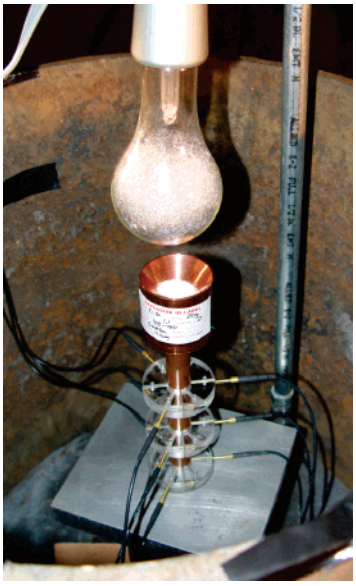

Figure 3. Assembly of a copper cylinder and a funnel containing K-6 explosive prior to addition of 0.020 g of SWNT and irradiation with a flashbulb. Pins surrounding the cylinder measure shock wave arrival time. Experiment was conducted in a specialty explosive tank.

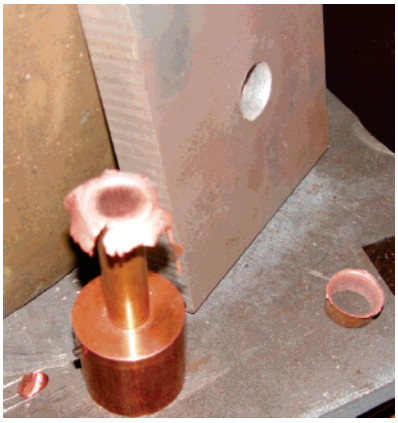

Figure 4. Assembly after detonation showing a destructed copper cylinder, funnel, and witness plate. Deformation in the witness plate distinguishes a detonation process from an explosion.

installed 5 cm above the funnel containing SWNTs and the K-6 explosive. With a duration time of 3 ms, the light power was 18 W/cm^2. Flashing resulted in initial deflagration of K-6 for approximately 1.5 min followed by an actual detonation process, the result of which is shown in Figure 4.

Post detonation analysis showed that a shock wave with an average speed of 6.8 km/s has ensued. For comparison, the detonation of a common ordinance explosive, such as RDX (cyclotrimethylene trinitramine), has a shock speed of 8.7 km/s at an approximate full density of 1.8 g/cm^3. In our experiment, the K-6 explosive was packed at an approximate density of 1.0 g/cm^3, well below its full theoretical density of 1.9 g/cm^3.[9] Further analysis also showed that the shock wave actually proceeded down the cylinder and then reflected from the witness plate before detonation occurred, a unique phenomenon known as retonation.[10]

Our demonstration of the possibility of ignition and initiation of energetic materials and nanotubes mixtures has important implications; whereas optical initiation of explosives can be achieved with laser power of GW/cm^2 on material samples of 0.5 mm in size, the reported results herein establish optical initiation with a light source of only several W/cm^2 on a large surface area of materials, thus forecasting greater suitability for application of optical triggering devices.

Finally, our encouraging results provide us with the opportunity of further studies to determine optimal parameters for optical initiation: materials composition, density, radiation power, wavelength, and pulse. While much is known about the physical properties of nanotubes,[11] it is the impurities (e.g., iron, nickel) that are believed to be the ignition reaction sites. It is with this class of SWNTs that optical spectroscopic studies could help discern some of these parameters (e.g., radiation wavelength). Such studies are currently underway and would be the subject of future reports.

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