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TITLE RECENT DEVELOPMENTS IN MICROSHELL®-TIPPED OPTICAL FIBERS AS HIGH-PRESSURE SHOCK DETECTORS

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ABSTRACT

We describe ongoing development and characterization of Microshell®-tipped optical fibers used as impact sensors. We observed a risetime of 15 ns when the probe is used to measure a detonation wave in PETN. We report successful development of two nondestructive tests, radiography and fluorescence, to check the integrity of the sensor. The sensor is now commercially available.

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INTRODUCTION

This paper describes recent results from our ongoing development of Microshell®-tipped optical fibers as high pressure shock wave sensors. The sensors, which have been previously described,[1] are commonly referred to as "optical pins" by analogy to the standard electrical "pins" which have been used in the shock wave community for many years. The sensor consists of a gas-filled (usually argon) Microshell® container glued to an optical fiber. When the Microshell® container is impacted, the contained gas is shock-heated and produces a bright light pulse that is transmitted via the optical cable to a photodetector, usually a streak camera, a photodiode or photomultiplier. This device is actually a miniaturized embodiment of the "flashgap" shock detection scheme described by Walsh and Christian.[2] Arrays of optical pins have been used in a variety of shock-sensing applications including ballistic impacts, detonation velocity measurements in explosives, and magneto-explosive generators.[3]

The optical pin has a number of advantages when compared to electrical pins for sensing shock arrival. First, in pulse-power environments, optical pins are immune to the electromagnetic pulse that overwhelms electrical pin signals. Second, optical pins are safe to use directly in explosives since they are completely passive. Unlike electrical pins, optical pins require no electrical bias or current carrying cables. Additionally, optical pins have a significant economic advantage because optical data are less costly to transmit and record than are electrical data. The cost of a streak camera capable of simultaneously recording 100 channels of optical data with subnanosecond resolution is only a few hundred dollars per channel, significantly less than the cost of 100 channels of electrical data recorded on oscilloscopes or fast digitizers.

CONSTRUCTION

Figure 1 is a schematic representation of a typical device. The spherical Microshell® gas container is epoxied or glued directly over the core of a freshly cleaved optical fiber. The duration, rise-time and intensity of the emitted optical pulse are influenced by the diameter of the shell. Decreasing the diameter of the shell decreases the optical pulse rise time and improves the spatial resolution. We find that 50-200 μm diameter shells work well in our experiments. Further, we optimize the coupling to the fiber by matching the core diameter of the fiber to the size of the Microshell® vessel or by over-filling the core acceptance angle.

The Microshell® gas containers are made from either glass or polymer materials. The choice of containers for these devices is set by the choice of gas, due to the diffusive gas-filling technique. Neon and argon are available in both glass and polymer shells while krypton is limited to polymer shells. To protect the shell from damage and to provide support during the experiment we usually add a protective sleeve and embed the shell in blackened epoxy filler. The epoxy serves two functions. First, it provides mechanical strength to the Microshell® gas containers. Second, being opaque, it prevents light "leakage" down the cable both before the shock arrival and after the shock has passed. We have found that opaque epoxy improves the optical signal to noise ratio upon shock passage.

RISE-TIME MEASUREMENTS

The optical pulse rise time has been measured in a number of different experimental configurations. One measurement is shown schematically in Fig. 2, where the array of optical pins in a cylindrical PETN powdered explosive have been imbedded perpendicular to the detonation direction in order to measure the detonation speed. In this experiment, the detonation

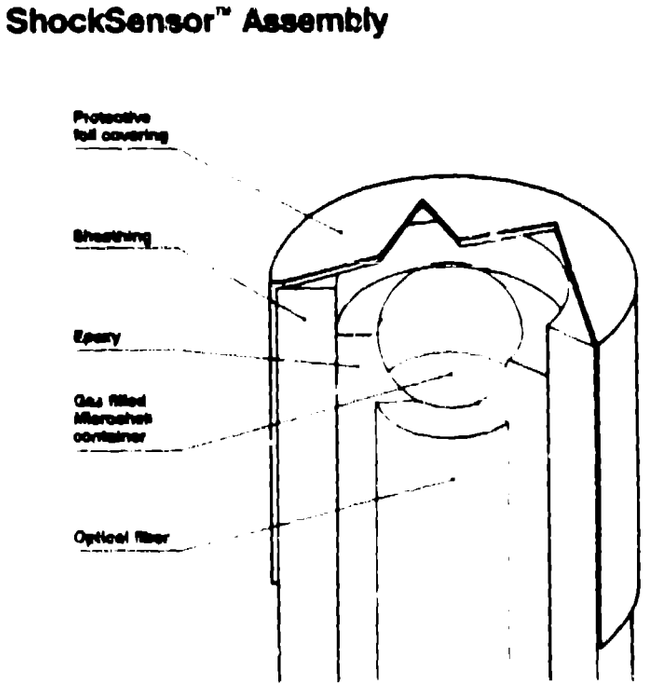

Fig. 1. A cut-away schematic of the optical pin construction.

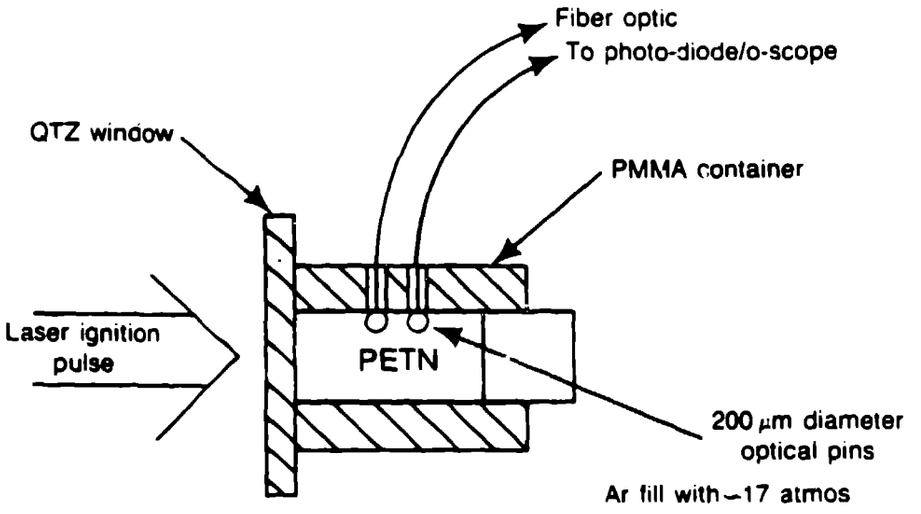

Fig. 2. Schematic of the laser-ignited PETN detonation velocity measurement showing optical pin configuration.

is launched at one end with a laser pulse. As the detonation wave advances, the optical pins are sequentially impacted causing the two optical pulses detected by a EG&G FND100 photodiode and a Tektronix 7904 oscilloscope. The photodiode/oscilloscope system has a rise time < 1 ns. Figure 3 shows the oscilloscope trace from the detonation measurement and optical pulses have a rise time of about 15 ns and an interval between them of 140 ns which, with the 1 mm pin spacing, gives a detonation velocity of about 7 km/sec. The detonation transit time across the 200 μm diameter Microshell® container is 28 ns, roughly twice the observed optical pulse rise time. Thus, the rise time of the optical pulse is considerably less than the transit time of the pressure impulse through the gas container.

A previous measurement with a much slower "BB" projectile (0.2 km/sec),[1] we had measured an optical pulse rise time of 80 ns with an associated transit time of 1 μm. In this low velocity experiment optical pulse rise time was only 8% of the transit time. We believe that these results support the physical model of the shock wave in the contained gas "reverberates" between the moving piston (the Microshell® container wall first impacted) and the down stream wall (last impacted). This interpretation is similar to the results of the experiments reported by Chaudhri, Almgren, and Person.[4]

Finally, we note that the optical signal level is quite small for low velocity impacts (requiring optical gain, a photomultiplier or image intensifier) but increases rapidly with increasing velocity as is expected for shock-heated gas radiating as a blackbody.

SPECTRAL OUTPUT

We have made a time-resolved measurement of the emission from an impacted optical pin by streaking (Hadland Photonics IMACON 790 streak camera) the output from a spectrograph (Hadland Photonics) in the region 400-700 nm. The projectile was accelerated to 1 mm/μs and allowed to impact the optical pin which was mounted in a wooden block several centimeters from the gun barrel. No emission or absorption lines were present in the spectra which supports the shock-heated gas being a blackbody radiation source. Unfortunately, the streaked spectrograph was not calibrated so we were not able to estimate an apparent temperature of the shock-heated gas. Calibrated experiments of this type are presently being pursued.

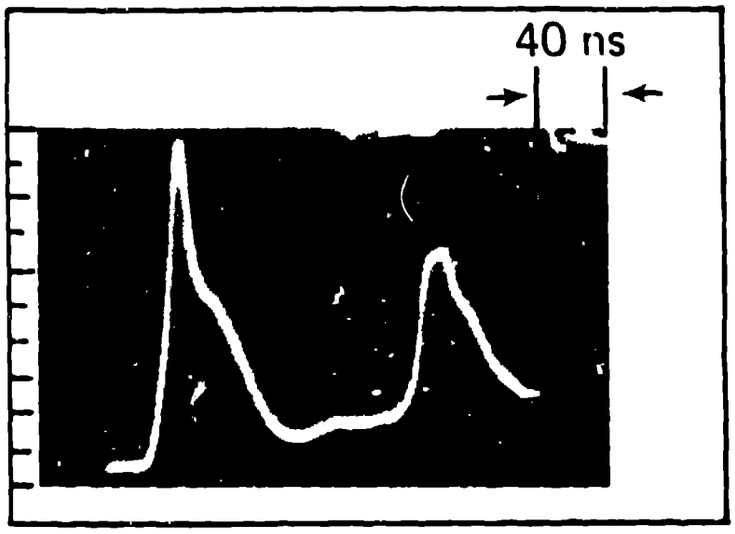

Fig. 3. Oscilloscope trace of optical pin light output from experiment of Fig. 2. The two optical fibers have been multiplexed onto one photodiode.

NONDESTRUCTIVE TESTING

Two methods have been developed for in situ verification of optical pin integrity. If the pins are to be used in an environment of low atomic number ("low Z") materials, e.g., explosives or plastics, the quartz optical fiber can be directly imaged in a contact radiograph. In higher Z environments the epoxy is doped with lead oxide or the Microshell® container is coated with a thin high Z film to indirectly image the pin. In addition to verifying the integrity of the shell and fiber tip, radiography is useful for determining pin positioning.

The second nondestructive test involves observation of an optical signal reflected from the sensor end of the fiber. Doping the epoxy or the Microshell® container itself with a fluorescent or phosphorescent dye allows one to detect respectively the frequency shifted or time shifted reflected probe signal. A most dramatic example of the fluorescence test is observed when an argon ion laser is used as the probe in conjunction with rhodamine dye as the dopant. Using only a beam splitter and optical spike filter, rhodamine fluorescence is easily detected at the receiving end of the fiber as verification of pin integrity. Fluorescent dyes are also being investigated as optical amplifiers of the shock signals whereby the dye red shifts the blackbody emission to a more sensitive region of the photodetector spectral response.

Time shifted signals can be observed if a phosphorescent dopant is excited by a pulsed optical probe given that the probe fall time is significantly faster than the phosphor decay time. If a suitable phosphor is used, i.e., one that absorbs at typical semiconductor emission wavelengths, the time shift test can be performed with commercially available optical fiber testing instrumentation (Tektronix Time Domain Reflectometer). The phosphor test is better adapted to field application since it does not require a monochromatic source or dispersing element.

USER APPLICATIONS

Optical pins are now commercially available[5] and are marketed under the trade name ShockSensor™. A variety of shock sensing applications are being explored by ShockSensor™ customers. These include applications as

witness plates for detonation, measuring shock velocities within the bulk of high explosives, tracing detonation-induced or impact-induced shock profiles in structures, and measuring the arrival time of projectiles or flier plates.

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5. This product is not endorsed by the Los Alamos National Laboratory, the University of California, or the U.S. Department of Energy.