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Pressure Sensors for Blasts and Shock Waves: State of Art

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Abstract: *There is a challenging field of sensing pressure in case of ballistic environment and shock waves. Traumatic brain injury (TBI) is a serious potential threat to soldiers who are exposed to explosions. In civilian applications as well we need to develop the pressure sensors for blast events so that Mining, Construction, Demolition, Pyrotechnics do not cause any problem to the society. This paper presents a review of pressure sensors for blasts and shock waves and an overview of semiconductor materials for sensing pressure for blasts and shock waves.*

1. INTRODUCTION

A blast creates a sudden increase in air pressure by heating and accelerating air molecules and immediately thereafter sudden decrease in pressure that produces intense wind. These shifts in pressure which are so fast can lead to Traumatic Brain Injuries [1]. Pathological studies show that TBIs cause damage to brain tissue in many areas of brain that temporarily or permanently impairs brain function.[2] The dynamic changes in pressure in atmosphere can be due to chemical or nuclear materials or electricity. The measurement of pressure in blast and shock waves is still an interesting area of exploration. Moreover a large pressure fluctuation lasts only a few milliseconds hence to accurately measure the rapid pressure change in the blast event, the sensors are required to possess a fast dynamic response. Civilian applications of various types of chemical explosives include: Mining, Construction, Demolition, Pyrotechnics and defense applications of explosives encompass: Aerial Bombs, Mines, Torpedoes, Breeching Operations, Ballistics, Tactical Missiles etc.

2. BLAST WAVES PRESSURE SENSORS

Air blast is a non linear process Fig 1 illustrates pressure v/s time graph for blast wave.

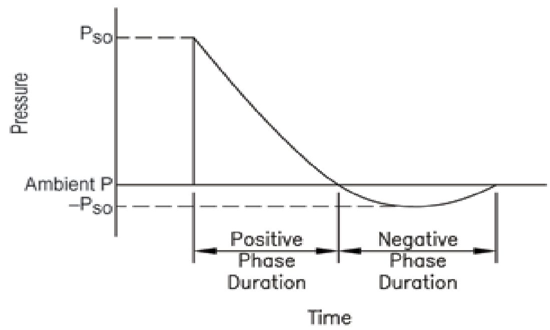

Figure 1 - Time After Explosion

Early development of Pressure sensor for blasts was done by Ballistic Research Laboratory (U.S.) and Royal Armament Research and Development Establishment (U.K.) around 1950s [3]. Early transducers for pressure sensing were done using piezoelectric crystal. Natural or cultured quartz and natural tourmaline are used as sensors in piezoelectric transducers. Quartz is inexpensive, stable and insensitive to temperature changes. Tourmaline provides sub microsecond response speeds which are valuable in blast transducers. Main advantages of piezoelectric pressure sensors include their small size, rugged construction, high speed of response and self generated signal [4]. But they had a limitation of influence of cable on their signal such as noise generated in cable, charge sensing amplifier noise level which increased with increase in cable length. Various designs were launched by industries to eliminate these errors. Another problem faced was interfacing the Pressure transducers with data acquisition systems. Moreover transducers can behave differently due to undesired environment that occurs with pressure as very high temperature, light, acceleration, strain as well as ionization products which lead to erroneous pressure indication as thermoelectric, photoelectric, and electromagnetic and other energy induced effects which can results in additive electrical signals which contaminate O/P signals. These act as noise. However methods were invented to eliminate this noise. Various sensors are reported in the Report given by Air Force Armament Laboratory for the period of 1987 to 1989. These covered piezoelectric sensor, photo elastic optic sensor, optical Fabry perot Resonator Pressure senor and shock tubes [5].

Time to time scientists are studying the effects of pressure on semiconductor electrical properties and exploring the possibility of using them in measuring pressures. Many theoretical studies were done on semiconductor materials showing change in band gap and electronic structure with pressurization [7-11]. Electrical resistance of $SrSi_2$ was measured which concluded that pressurization results in reduction of energy gap. Band gap of Cdse decrease was studied with the pressure increasing and decreasing trend [12]. In 2010 Si, GaAs and AlAs bulk semiconductors were studied for the effect of hydrostatic pressure on electron band structures and dependence of energy gaps [13].

SnO2, TiO2 ; ZnO nano materials revealed pressure sensing properties with response times 2.5 s, 5.6s and 4s for SnO2 TiO2, ZnO respectively [14]. Development of piezoresistive transducers used for air-blast pressure measurements. Using MEMS technology enables steady-state operation at temperatures to greater than 1000 °F [15-16] while also enhancing transducer performance in thermal-transient environments..For TBI studies, measurement of blast events needs sensors with very high response time. Chavko et al measured the shock wave in the rat brain has a rise time of at least 0.4 ms from 0 to50 Kpa [18] so we need pressure sensor with response time more than this. Even Fiber Optics has shown great relevance in measuring the pressure in ballistic environment [18]. Fiber optic traducer was fabricated of a single fiber optic cable which terminates in a small cavity capped with a diaphragm. Laser light is directed along the cable and reflect from the diaphragm due to external pressure. This will result in phase shift in wavelength of reflected light which can be recorded and calibrated against pressure diaphragm diameter 100 micrometer [19]. An ultra fast fiber optics pressure sensor based on Fabry Perot principle was reported. To measure pressure transients pressure sensor should have higher frequency and high spatial resolution. Resonant frequency of sensor was 4.12 MHz and rise time of 120ns [20].

3. SHOCK WAVES PRESSURE SENSOR

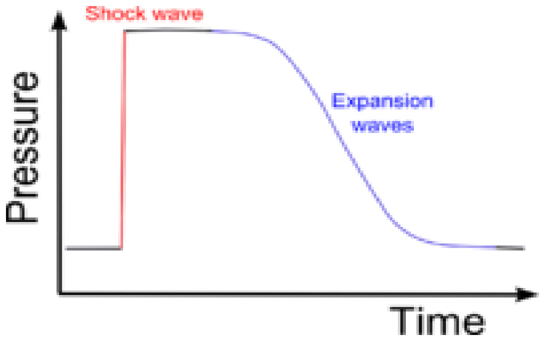

Fig2. *Pressure v/s Time for shock Wave*

There are many ways to generate micro shock waves. Miller has used shock wave technology for destruction of renal calculi through an endoscope [21]. Shock waves are also used for needleless during delivery into human skin and DNA transfer in biological targets [22]. Presently there are enormous applications of shock waves in industries as well as biomedical applications. Ultrasonic shock waves are widely used in lithotripsy for the extra corporeal disintegration of Kidney stones [23]. Liquid shock tubes are used to generate shock waves non explosively.

Pressure sensor based on ALGaAs thin films of semiconductor material was fabricated in lithotripters 2 $x10^4$ pressure pulsating of 40 Mpa in amplitude were sensed with rise time less than 0.1 µs. The sensitivity of sensor was doubled by modifying the concentration of components (Ga As and Al As) and their distribution in the epitaxial film [24].

A fiber-based optical pressure-sensor, (2007) made using semiconductor nanocrystal quantum dots (NQDs) as the active transducing material, provides response time fast enough for shock wave measurements. For NQDs, the shift in band gap as a result of applied pressure can be observed as a shift of the photoluminescence (PL) peak. Further, the shift of the principal absorbance feature allows pressure measurements faster than those obtainable by following the PL peak [25].

Germanium based semiconductor pressure transducers for measurement of shock waves in the range 10^3 - 10^4 atm are reported [26] and give the results of pressure measurements with it in a liquid-filled shock tube.

4. CONCLUSION

Considering the above mentioned facts related to pressure sensing in blast and shockwave the accurate transducers is the need of hour. This paper is just a review of different pressure sensors in the phase of development. It is basically to discuss the development of semiconductor based sensors for blast and shock waves. It is hoped that this work will serve as reference to others working development of semiconductor sensors in measurement of dynamic pressure.

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