A SEMICONDUCTOR PRESSURE TRANSDUCER FOR MEASUREMENT OF STRONG SHOCK WAVES ($\geq 10^3$ atm) IN LIQUID

V. K. Kedrinskii, R. I. Soloukhin, and S. V. Stebnovskii

Zhurnal Prikladnoi Mekhaniki i Tekhnicheskoi Fiziki, Vol. 10, No. 4, pp. 92–94, 1969

We describe a germanium-based semiconductor pressure transducer for measurement of shock waves in the range 10^3–10^4 atm and give the results of pressure measurements with it in a liquid-filled shock tube.

Pressure in shock waves is usually measured by piezoelectric transducers in which the sensitive element is a quartz or tourmaline crystal or one of the piezoceramics—barium titanate or lead titanate-zirconate [1, 2]. Owing to the low strength of these elements such transducers cannot be used to measure pressures of more than 10^3 atm, and the use of junction devices of various kinds to reduce the shock significantly alters the variation of pressure with time and, hence, can be justified only in the case in which the integral characteristics of the process are required.

In [3] we found it necessary to measure pressures of 10^3–10^4 atm and suggested that strong shock waves might be measured with germanium-based semiconductor pressure transducers, whose bulk conductivity (or the conductivity of a contact with a p-n junction) depends strongly on the pressure. The main factor responsible for the change in conductivity of germanium with pressure is the change in the width E of the forbidden band. This change, which was determined experimentally in [4], is approximately 0.1 eV for a pressure change of 10^4 atm and leads to a change in the carrier concentration, which is an exponential function of E, by almost an order of magnitude.

Below we describe one of the possible designs of a semiconductor transducer for pressure measurement in a liquid-filled shock tube in which shocks are produced by the collision of a liquid column accelerated to a particular velocity in an evacuated channel with a stationary liquid column [3].

A diagram of the transducer and the method of mounting it in the shock tube is shown in Fig. 1, where 4 is the steel chamber containing the liquid, 2 is the contact, 5 is the shock front. The sensitive element 1, made of germanium-silicon alloy (8% Si), has dimensions 1 × 1 × 0.5 mm and is embedded in epoxy resin 3 (the filler is electrocorundum powder), which is then polymerized. The element 1 forms part of the end face of the shock tube.

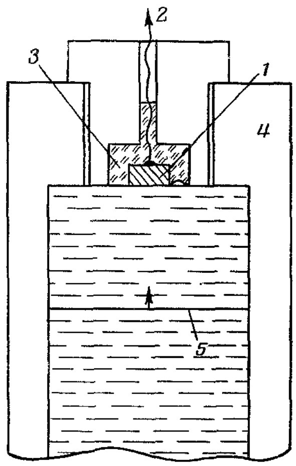

Fig. 1

The electrical circuit of the transducer is shown in Fig. 2, where R is the load resistor, C = 0.6 μF, B is a storage battery, and T is the transducer.

The semiconductor transducers were used to measure pressures in shock waves in the range 300–5000 atm. The lower limit of this range was set in the experiments by the sensitivity of the amplifier A used in the circuit

(0.25 cm/mV). The sensitivity of the measuring circuit was at least 1/300 mV/atm.

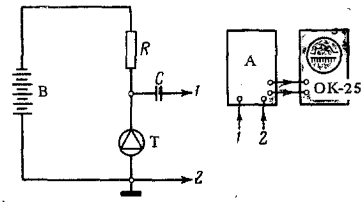

Fig. 2

A typical pressure oscillogram is shown in Fig. 3 (10-μsec time marks). The minimum rise time of the wave in the experiments was ≤ 2 μsec and depended on the presence of the resin layer on the surface of the semiconductor element, since the natural frequency of the element, in which the velocity of sound is 4930 m/sec (along the direction of motion of the shock wave), is about $3 \cdot 10^7$ Hz. This makes it possible in principle to resolve the front into fractions of microseconds.

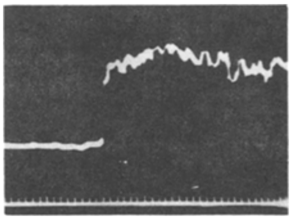

Fig. 3

The pressure fluctuations behind the front, revealed by the oscillograms, had a lower frequency and depended on the nature of the process under investigation.

Germanium-based semiconductor pressure transducers are distinguished by their low resistance—usually only a few hundred ohms. This makes the proposed transducers very free from interference.

These transducers can be calibrated by the detonation of explosives in a liquid-filled shock tube [3]—from the velocity of the liquid column u at the moment of impact:

$$p = \frac{1}{4} u^2 \left[\frac{1}{\rho_0} - \frac{1}{\rho}\right]^{-1}$$

("liquid-liquid" collision), where ρ and p are the density and pressure, respectively, on the shock front, or by the static method.

The results of calibration by the static method (with oil) are shown in Fig. 4 in the form of a plot of the relative resistance of the transducer [germanium-silicon (1) and contact with p-n junction (2)] against the pressure at 18° C. The resistances of the elements were 471 and 747 ohms, respectively. The plots are linear, and in addition, the plot for the first of the elements is linear up to 20,000 atm, according to the data of [4]. The presence of a contact with a p-n junction greatly increases the sensitivity of the measuring circuit (Fig. 4), but the mechanical strength of the transducer is reduced.

Figure 5 shows an oscillogram of the pressure and a diagram of the interaction of the shock waves in the shock tube [3]. When a "liquid-liquid" collision occurs, shock waves 1 and 1' travel through the stationary and decelerated media, respectively. The transducer T, mounted on the end of the discharge tube, registers the first reflected wave 2. The increase in pressure behind the wave front 2 is due to the gradual compression of the decelerated liquid which continues after collision. There must be a pressure drop behind the shock front 2' reflected from the piston owing to the movement of the piston under the load 1'. This effect is registered by the transducer after collision of the waves 2 and 2' at point S (second jump on oscillogram). The process is then repeated. The third pressure jump on the oscillogram is due to reflection from the end of the tube of the wave produced by the second collision (S') of the reflected waves.

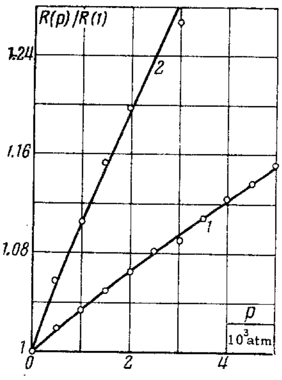

Fig. 4

As Fig. 5 shows, the pressure oscillogram accurately conveys all the processes occurring after collision of the ·uid columns.

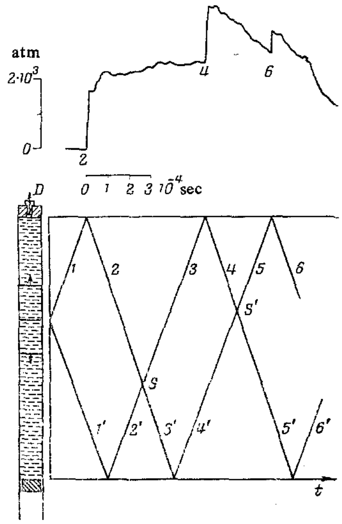

Fig. 5

The proposed transducer operates reliably and can be used for pressures much higher than the limit of $5\cdot10^3$ atm attained in the experiments. We have also used this type of transducer in the form of a probe similar to that described in [1, 3].

The authors are grateful to B. I. Zaslavskii for interest in the work, recommendations, and useful comments.

REFERENCES

1. I. B. Sinani, "Tourmaline indicators of shock waves in liquids," Pribory i tekhnika éksperimenta, no. 4, 1957.

2. R. I. Soloukhin, "A pressure pulse transducer," Pribory i tekhnika éksperimenta, no. 3, 1961.

3. M. I. Vorotnikova, V. K. Kedrinskii, and R. I. Soloukhin, "Shock tube for the investigation of unidimensional waves in a liquid," Nauchn. tekhn. probl. goreniya i vzryva, no. 1, 1965.

4. W. Paul and D. Warschauer, "The role of pressure in semiconductor research," collection: Solids under Pressure [Russian translation], Mir, Moscow, 1966.

3 March 1969

Novosibirsk