AIP Review of Scientific Instruments

Variable Gap Capacitive Detector for the Measurement of Ultrasonic Displacement Amplitudes in Solids

R. D. Peters, M. A. Breazeale, and V. K. Paré

Citation: Review of Scientific Instruments **39**, 1505 (1968); doi: 10.1063/1.1683147
View online: http://dx.doi.org/10.1063/1.1683147
View Table of Contents: http://scitation.aip.org/content/aip/journal/rsi/39/10?ver=pdfcov
Published by the AIP Publishing

Variable Gap Capacitive Detector for the Measurement of Ultrasonic Displacement Amplitudes in Solids*

R. D. Peters,† M. A. Breazeale,‡ and V. K. Paré
Solid State Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee 37830

(Received 8 March 1968; and in final form, 3 June 1968)

A variable gap capacitive detector has been developed for displacement amplitude measurements of longitudinal ultrasonic waves in the frequency range 5 to 100 MHz. The gap spacing is controlled by differential gas pressure. With this device it is possible to maintain a constant detector capacitance for measurements of the temperature dependence of the third order elastic constants. This improves the precision of the measurements considerably.

A CAPACITIVE detector for the measurement of absolute ultrasonic strain amplitudes in solids has previously been developed.[1] In order to achieve the required wave amplitude sensitivity of 10^{-10} cm, the electrode must be placed approximately 5 μ from the sample, both surfaces being optically flat. A bias voltage of about 100 V is then applied between these surfaces. When the sample end is forced to vibrate by an ultrasonic pulse, a voltage is generated which is simply related to the vibration amplitude and to the electric field strength in the gap.

In order to measure the temperature dependence of the third order elastic constants, this detector was recently adapted to a cryogenic apparatus. In spite of attempts to match thermal expansion coefficients and to achieve a stable insulator–electrode configuration, it was not possible, with this detector, to maintain the gap capacitance constant to better than ±10% over a temperature range of 200°. As explained below, these variations caused a decrease in measurement accuracy.

As originally used,[1] the detector was connected directly to a preamplifier having high input impedance. Thus loading of the detector (considered as a signal source) was negligible. Since the preamplifier could not be installed in the cryostat, the detector signal had to be brought out on a coaxial transmission line of appreciable length. To reduce standing wave effects and to improve the noise figure it was necessary to omit the preamplifier and to match the line as closely as possible to the 50 Ω input impedance of the tuned fundamental and second harmonic amplifiers. The resulting 50 Ω load on the detector reduced the output by an amount which depended on the gap capacitance. Thus, during operation it was necessary to monitor the changes of gap capacitance with temperature and then apply appropriate correction factors. It was found that during low temperature operation the gap capacitance frequently attained values for which the correction factors were not adequately precise.

For this reason a capacitive detector has been developed whose gap spacing can be controlled pneumatically during operation in a cryostat. Figure 1 shows the detector and control system. The sample rests on a Cu–Be alloy (98% Cu, 2% Be) ground block which was chosen both for its resilient nature and because its coefficient of thermal expansion is nearly that of pure Cu. The important part of the ground block is the washer-shaped flexible ring created by undercutting the block 6.35 mm to a thickness of 0.38 mm. This ring functions as a diaphragm so that the spacing between sample and electrode is controlled by the externally applied pressure difference P_2-P_1. Figure 2 shows the nearly linear relationship between gap spacing and pressure difference as well as the relationship between

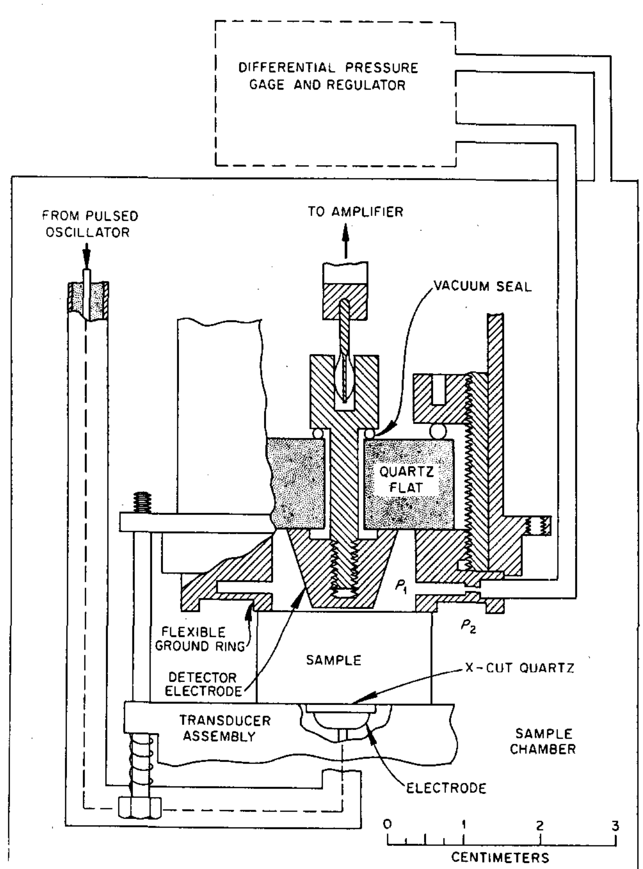

FIG. 1. Variable gap capacitive detector.

* Research sponsored by the U. S. Atomic Energy Commission under contract with Union Carbide Corporation.

† Oak Ridge Graduate Fellow from the University of Tennessee under appointment from Oak Ridge Associated Universities.

‡ Consultant from the University of Tennessee, Knoxville, Tenn.

[1] W. B. Gauster and M. A. Breazeale, Rev. Sci. Instr. 37, 1544 (1966).

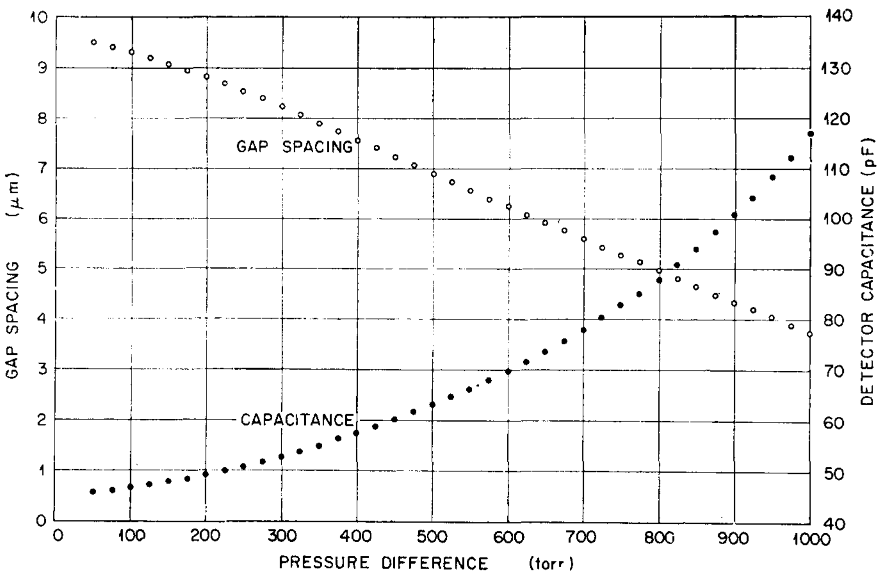

FIG. 2. Detector gap and capacitance vs pressure difference between sample and electrode chambers.

capacitance and pressure difference. Repeated measurements showed no detectable hysteresis, indicating that there is no apparent yielding of the ring.

Pressure differential regulation is provided by a conventional manual mechanical regulator (not atmospheric referenced), and pressure differences are read on a differential gauge which operates in the range 0–2000 Torr. P_1 is actually a rough vacuum and P_2-P_1 changes are accomplished mostly by changes in P_2. The vacuum is maintained by an O-ring seal (of indium when in the cryostat) and the seal between polished surfaces.

Initial setup of the assembly is done as follows: With the detector electrode tightened against the quartz flat on its three support points, the ground ring, detector electrode, and outer ring of the ground block are all polished optically flat. The detector electrode is then removed and its support points are selectively polished to obtain the desired zero pressure gap spacing while maintaining parallelism, which is checked with another optical flat and monochromatic light. The same method is used to be sure that parallelism is maintained when pressure is applied to control the gap spacing. Maintenance of parallelism depends, of course, on careful machining of the flexible ground ring.

The detector shown in Fig. 1 has been operated between 300 and 77 K with a gap spacing of 6.73 μ. (This spacing corresponds to 64.5 pF measured on the capacitance bridge used to monitor the gap spacing.) The pressure differences required to maintain this gap varied from 500 Torr at 300 K to 1000 Torr at 77 K.

By adjusting the pressure differential to keep the detector gap capacitance at a constant value, it is now possible to obtain all temperature dependence data relative to room temperature values which can be determined with reasonable accuracy.[2] Since the characteristics of the transmission line have been found to be stable against temperature variations, the only variable component of the detecting system response is the gain of either amplifier. Each is checked periodically by applying a calibrated signal source. Thus, the relatively small changes of third order elastic constants with temperature can now be followed with good precision. This could be done by noting the changes in output of the fundamental and second harmonic amplifiers; however, it is better to maintain constant amplifier output by adjusting the value of bias voltage on the detector. The bias voltage can be measured precisely; its relation to detector output is precisely linear.

A test of the precision of the apparatus was made as follows. Keeping the fundamental amplitude and the capacitance constant, the change in the second harmonic generated by a [100] copper sample between room temperature and the ice point was observed. Although this small temperature variation produced a measured change in the third order elastic constant C_{111} of only about 2%, this change was easily observed and was noted to be in a direction consistent with the results of Salama and Alers.[3]

---

[2] W. B. Gauster and M. A. Breazeale, Phys. Rev. **168**, 655 (1968).
[3] K. Salama and G. A. Alers, Phys. Rev. **161**, 673 (1967).