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STABLE PRESSURE TRANSDUCER

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Abstract

This report describes the recent work on the development of a capacitive pressure transducer which uses a solid dielectric material. We are continuing the search for a pair of dielectric materials which will produce capacitors having the same temperature dependence but markedly different pressure dependences, so that the overall temperature dependence of the device can be minimized.

We have concentrated on anisotropic materials whose properties can be tailored within its range by using the appropriate cut from the crystal. This particular effort has not been fruitful. We have been fortunate, however, in finding that the perpendicular and parallel cuts of calcite ($CaCO_3$) come close to satisfying our conditions and we are pursuing possible further development of the device utilizing this pair.

Progress on the fabrication of the automatic capacitance bridge to be used with this device is discussed.

Introduction

We are attempting to develop a capacitive pressure transducer in which the capacitor consists of metallic electrodes deposited directly on a solid dielectric sample. The principle objective in developing a device of this type is that it should possess long term stability, in that one cannot envision irreproducible changes occurring in the measured property under hydrostatic conditions. Initial attempts at such a device using CaF_2 as dielectric material proved this contention. The desired precision for the device of better than $1:10^4$ at 70 MPa (10,000 psi) was approached with CaF_2. Unfortunately, to achieve this resolution with CaF_2 required that the device be thermostated to within 1 mK. To overcome this drawback a search was made for a material with a smaller temperature coefficient of capacitance while having as large or larger pressure coefficient. No dramatic improvements have been found. In our report of July, 1974 and at the CCG meeting in August, 1974 we set forth an idea for circumventing the temperature dependence of the device. If two materials could be found for capacitors, which would have widely differing pressure dependences but nearly identical temperature dependences, they could both be placed in the pressure vessel but in opposite arms of the measuring bridge so that their individual temperature dependences would cancel. No known pair of materials met the requirement. It was decided that the search for an appropriate pair should concentrate on the measurement of anisotropic materials. In this way, if cuts of crystals taken parallel and perpendicular to the crystalline axis gave a temperature dependence of the capacitance spanning that of another material, they

could be matched by taking the appropriate cut from the anisotropic crystal. This work is currently in progress but has not produced the desired results. We have been fortunate, however, in finding that the parallel and perpendicular cuts from calcite ($CaCO_3$) come close to meeting our requirements and may be considered an interim solution to the problem.

EXPERIMENTAL DATA

In looking for materials with the appropriate properties to form a capacitive pair for the pressure transducer, we surveyed all existing data and found only one good possibility. The temperature dependence of a-cut paratellurite (TeO_2) fell midway between that of the a- and c- cuts of sapphire so that a match could be made with a 45° cut from sapphire. The predicted pressure dependence of the pair would have been about the same as CaF_2. Our new measurements on sapphire show however, that the temperature dependences reported earlier were much to high and the new values for sapphire do not overlap on paratellurite at all. With this result, we were left with no combinations which would fulfill our requirements so we have been forced to continue making measurements on all available materials. The current set of results are summarized in Table I and are discussed below. In Table I the dielectric constants, ε, were determined from the capacitance using the effective area of the electrode and the measured thickness of the sample, the value has an uncertainty of about 2%. The Quality factor, Q.F., is the absolute value of the ratio of the pressure dependence to the temperature dependence values for CaF are included in the table for comparisons.

The temperature and pressure dependences for the quartz samples (Valpey-Fisher Corp.) are both small giving good quality factors for the z and y cuts, but the magnitude of the pressure dependence is too small to make the material useful. In addition, as was noted in an earlier report, there is a long (as much as 24 hrs.) relaxation phenomenon in quartz which occurs after pressure changes and makes this material unsuitable for our purposes. The relaxation is particularly prevalent in samples with a component of the z-axis parallel to the field and we believed it to be associated with the piezoelectric properties of the crystals.

The capacitance measurements with the sapphire samples (Crystal Systems Inc.) were well behaved: reproducible, no relaxation phenomenon and low loss. This was not true of the ceramic Al_2O_3 sample, Lucalox (obtained from John Fontanella, US Naval Academy), which was very lossy and kept drifting about.

The MgF_2 samples (Optivac, Inc.) had a relaxation phenomenon that appeared to be associated with impurities. The loss component of the capacitive measurement with the field parallel to the c-axis was initially a factor of 10 larger than in the perpendicular direction, an effect that has been noted with impure MgF_2 crystals by other investigators. This loss component (though not large on an absolute basis, $\tan \emptyset \approx 0.0007$) slowly diminished over the four weeks that the sample was in the apparatus and was constant at the end of that time. The in phase component also changed by a small but significant amount as the out of phase component changed. It is thought that this effect may have been due to the dissolving of precipitated impurities when the sample was warmed as electrodes were deposited, the impurities then slowly reprecipitated. It would appear that this material would still be suitable for device use.

GGG, gadolinium gallium garnet (Allied Chemical Corp.) was well behaved in all respects. The two As_2S_3 glasses (both obtained from Fontanella at different times) were well behaved. The loss component was larger than most crystalline samples but was reproducible. The same comment applies to the other two glasses (obtained from Fontanella and Roy Waxler, NBS) although the loss component in these was considerably larger. The zirconate ceramic (General Electric Co., Ltd.) has an excellent quality factor but this material was very lossy and measurements tended to drift considerably.

The capacitance measurements with the calcite, $CaCO_3$, samples (Karl Lambrect Corp.) were well behaved with very small loss components. One must use care in depositing electrodes on this material, however, as it was noted that small splatters of the aluminum coating caused pieces of the crytal to spall out.

In Fig. 1 we have plotted the pressure dependence versus the temperature dependence of the capacitance of each material together with values from earlier work on other materials. Values for anisotropic materials are joined by a line indicating the locus of values which could be spanned by the different crystal cuts of that material. What we want to find on this plot are two materials which lie on a vertical line but are widely separated from each other on that line. As can be seen in the figure the only overlaps that have significant vertical displacement occur with paratellurite, TeO_2. The new sapphire data no longer overlap on this material and $MgF_2 \perp$ is the only material that does gives a sizable vertical displacement (28 TPa^{-1}). This combination would give considerably less pressure resolution than is obtainable with a CaF_2 capacitor.

The best immediate prospect is with the two cuts of calcite. They have very nearly the same temperature dependence and their pressure dependences are widely separated. The relevant quantities for comparison of a calcite pair with CaF_2 is the differences in the temperature and pressure dependences of the two cuts. These are shown in the last line of Table 1. The calcite pair gives an improvement over CaF_2 of about 60% in the pressure dependence and more than 2 orders of magnitude in the temperature dependence so that the quality factor is up by a factor of about 230. With a device using a calcite pair it should be possible to resolve 700 Pa (0.1 psi) while thermostating the device with an accuracy of only ±0.05 K. A drawback with using this particular pair is the large values of their individual temperature dependences. As a result, small temperature differences between the two capacitors from any thermal gradients will produce a correspondingly larger apparent pressure change.

CONTINUING DEVELOPMENT

We have finally acquired some TeO_2 samples so that we may measure this material in our laboratory to check on its values. Unfortunately, the samples are an odd size (0.6") and will require special handing. We have samples of several other materials on hand for future measurement and are continually looking for more in the hope of finding a better combination.

We are beginning design considerations of a pressure vessel and thermostat arrangement which could be used with a calcite-pair pressure transducer.

AUTOMATIC CAPACITANCE BRIDGE

Progress is continuing on the limited-range automatic capacitance bridge being constructed for use with the pressure transducer. The analog portion of the bridge circuitry is now essentially complete. After a considerable time was spent tracing done noise problems originating from faulty components we have a bridge capable of resolution in the range of $1:10^9$. Although some small improvements are still contemplated on this portion of the bridge, all efforts are now being directed toward the digital portion. After some recent design changes, new drawings are complete and work has begun on assembly of the digital counter and digital control parts of the bridge.

Table I

Dielectric Material	ε	$\frac{d \ln c}{dP} \times 10^{12}$/Pa	$\frac{d \ln c}{dT} \times 10^{6}$/K	QF
CaF_2	6.8	-37.6	262.7	0.143
Quartz				
X-cut	4.5	7.7	-2.4	3.2
Y-cut	4.5	7.7	-3.5	2.2
Z-cut	4.7	-1.9	33.4	0.056
XLZ 45°	4.6	7.7	10.4	0.74
YLX 45°	4.6	2.8	20.4	0.14
Sapphire				
(0001)	11.5	-11.6	136.3	0.085
$(10\bar{1}0)$	9.4	-10.6	95.8	0.111
(1120)	9.5	-10.7	95.9	0.112
$(1\bar{1}02)$	10.0	-10.6	107.8	0.098
Lucalox	10.2	-52.8	146	0.36
MgF_2 $\perp$	5.5	-13.26	172.3	0.077
MgF_2 $\parallel$	4.8	-21.13	199.4	0.106
GGG	12.6	-17.0	127	0.134
As_2S_3(A)	7.4	114	63.4	1.80
(B)	7.7	112	78.2	1.43
Glass(F)	6.5	-34.3	139	0.162
Zirconate Ceramic	34.4	-51	16.8	3.0
Calcite $\perp$	8.0	12.2	327.2	0.037
Calcite $\parallel$	7.7	72.0	329.0	0.219
Calcite pair	—	59.8	1.8	33.

FIGURE CAPTION

Fig. 1. The pressure dependence as a function the temperature dependence of capacitors of various materials. Values for anisotropic materials with the electric field parallel and perpendicular to the crystalline c-axis are plotted and the line connecting them represents the values attainable with crystals cut at intermediate angles.

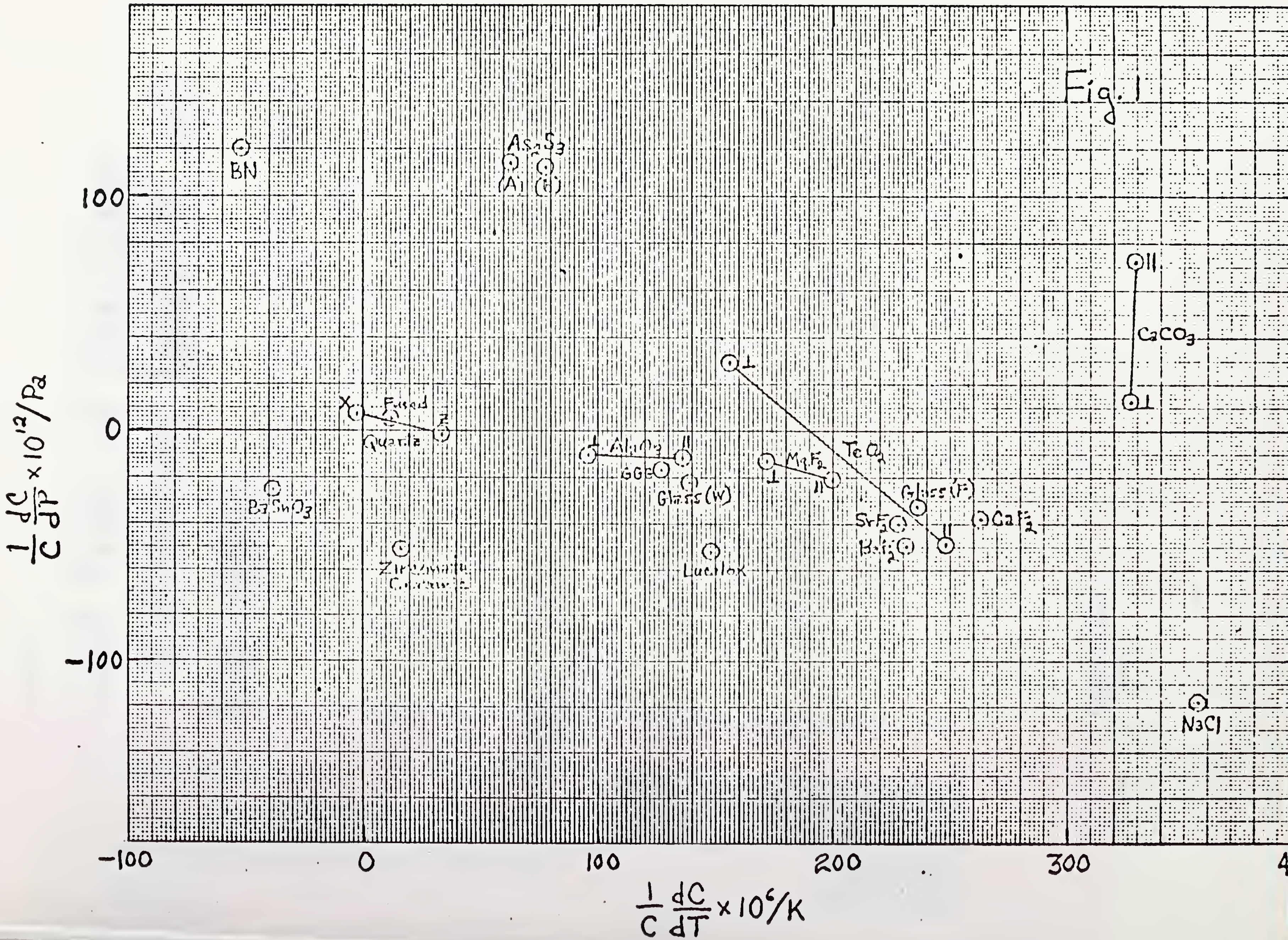
Fig. 1
BN
As_2S_3
$BaSnO_3$
TeO_2
MgF_2
Al_2O_3
GGG
Glass (W)
Glass (F)
SrF_2
CaF_2
$CaCO_3$
NaCl
100
0
-100
-100
0
100
200
300
$\frac{1}{C}\frac{dC}{dP} \times 10^{12}/Pa$
$\frac{1}{C}\frac{dC}{dT} \times 10^{6}/K$