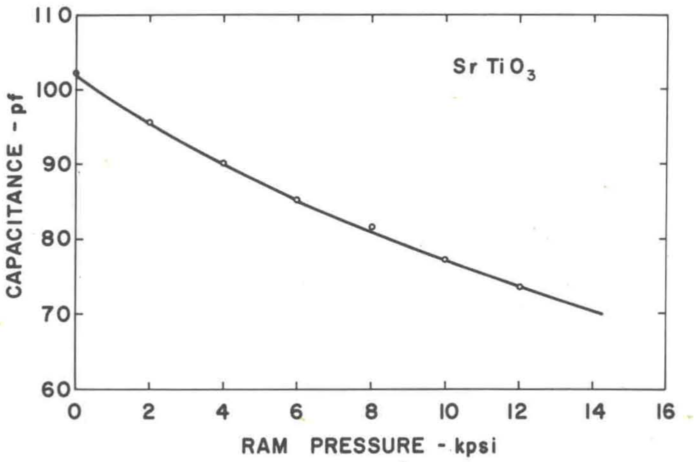

Fig. 15 Capacitance versus ram pressure for single crystal $SrTiO_3$ measured at room temperature

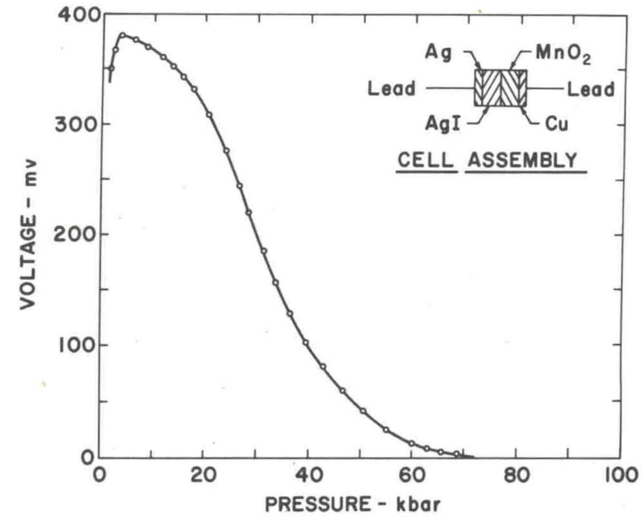

Fig. 16 Sample arrangement for resonant frequency technique for measuring dielectric constants uncer pressure. The sample material is prepared in the form of a cylinder, and two cuts are made parallel to its axis. The center slab is made into a thin parallel plate condenser. A wire coil is wound on the assembled sections. The ends of the coil are connected, one each, to the plates of the condenser. Pick-up coil is not shown

time the circuit is triggered, a complete trace of the hysteresis loop appears on the scope. With such a device currents of the order of hundreds of amperes can be passed through 0.015-in-dia wire without burning it.

Unlike the Curie point, it is well known that saturation magnetization can be quite sensitive to strain, especially for stresses beyond the elastic limit. Therefore, in apparatus utilizing solid pressure-transmitting media where deviations from truly hydrostatic conditions do exist, sprious changes in magnetization with pressure may result. One must then be very careful in interpreting data obtained in such apparatus. This point is emphasized by the data shown in Fig.14 which compares the relative change in flux density with pressure for 70 pct Fe-30 pct Ni measured in a hydrostatic apparatus (16) and in the cube unit. The same material (0.006-in-thick foil) was used for both experiments. To reduce hysteresis losses due to eddy currents, the cores consisted of laminations of the alloy separated by layers of insulation. In the hydrostatic case, the insulator was paper. The core was wrapped with a thin layer of masking tape on top of which the primary and secondary were wound. For the cube-unit experiment, the sample was prepared as follows: The laminations were separated by 0.006-in-thick laminations of $AgC\ell$, and the stack was encapsulated in a thin $AgC\ell$ casing. The primary and secondary were wound on that, and the assembly was again encapsulated in $AgC\ell$. The center portion of the toroid was filled by an $AgC\ell$ disk. Two coaxial cables served as leads.

With hydrostatic pressure, B decreases linearly and reversibly over the whole pressure range covered. In the nonhydrostatic case most of the change occurs in the first 2-3 kbars and the reversibility is as shown. A second application of pressure reproduces essentially the same behavior. It is interesting to note that the reversibility curve parallels somewhat the hydrostatic data.

The example in Fig.14 is probably an extreme case, but it serves to emphasize that care should be exercised in interpreting magnetization data obtained in apparatus where pressures are not purely hydrostatic. Other examples are available in the literature. For example, the magnetization of nickel shows a fairly large increase with pressure for measurements in a nonhydrostatic apparatus (19), but decreases with hydrostatic pressure (20). On the other hand, there are materials, including some ferrites, such as manganese zinc ferrite whose magnetization does not appear to be significantly affected by small deviations from hydrostaticity. For these, physically meaningful pressure results can be obtained.

DIELECTRIC-CONSTANT MEASUREMENTS

Accurate dielectric-constant measurements of normal dielectrics at high pressures are very difficult to make even in hydrostatic apparatus. The difficulties are much more severe in nonhydrostatic systems. In addition to the usual problems of edge effects, stray capacitance, and contributions from the surrounding medium, two major difficulties are encountered in the high pressure experiment. First, and perhaps most severe, is the change in lead capacitance. For low dielectric-constant materials, this change completely overshadows the desired effect. In hydrostatic apparatus this effect is reasonably well reproducible so that it can be accounted for. No great accuracy is achieved, but meaningful data can be obtained. In nonhydrostatic apparatus the effect is random. The second difficulty is the excessive sample deformation and dimensional changes encountered in most nonhydrostatic devices.

There have been only a few pressure measurements of the dielectric constant of normal dielectrics (21,22), and these were made in hydrostatic apparatus. A considerable amount of work has been done on the effects of pressure on the dielectric constant of ferroelectrics (23,24). These dielectric materials possess very interesting properties including high dielectric constants which exhibit large pressure coefficients. Again, all these measurements have been made in hydrostatic systems. Ferroelectric properties are very sensitive to strains; therefore, measurements in nonhydrostatic apparatus generally would have little or no physical significance.

Despite all the aforementioned difficulties there is one class of dielectrics which offers the opportunity for dielectric constant measurements in suitable solid media apparatus. This class constitutes the perovskites in their nonpolar, or paraelectric, state. Below the Curie point, these materials exhibit ferroelectric and antiferroe ectric properties. Above the Curie point, they are normal dielectrics with the cubic perovskite structure and possess high dielectric constants which are pressure sensitive. Because of their high constants, sample dimensions can be chosen so that the capacitance of the sample is considerably larger than that of the leads. This, along with the use of coaxial cable and the negligible sample deformation in our apparatus, makes it possible for us to study the pressure dependence of the dielectric constant of these materials.

We have made measurements on single crystal $SrTiO_3$ and ceramic $BaTiO_3$. The preliminary results are consistent with the hydrostatic data. $SrTiO_3$ is cubic at room temperature and $BaTiO_3$ transforms to the cubic form above ~120 C at atmospheric pressure. The samples are prepared in the form of thin parallel plate condensers and their capacitance is measured as a function of pressure and temperature. Fig.15 shows the capacitance of a $SrTiO_3$ crystal as a function of ram pressure, measured at room temperature and 10 kc/sec. We did not attempt any quantitative analysis of the data in Fig.15 because the coaxial cable into the pressure chamber had a capacitance of the same magnitude as that due to the sample, and it was quite lossy and became more so under pressure. For this purpose, it is better to use a cable with two thin center conductors for leads. Fig.15, however, shows the smoothness of the data and exhibits the same behavior as is observed under hydrostatic conditions where it is found that the dielectric constant, ϵ, follows the relationship:

$$\epsilon = \frac{k}{P-P_o} \tag{5}$$

where k and P_o are constants obtained from the slope and intercept, respectively, of a $1/\epsilon$ versus P plot. This is of the form of the well-known Curie-Weiss law

$$\epsilon = \frac{k^*}{T-T_o} \tag{6}$$

where k^* and T_o correspond to k and P_o, respectively. The data in Fig.15 follow equation (5). A plot of 1/C versus P is a straight line.

We have been recently considering a novel approach for studying dielectric constants which does away with difficulties due to change in lead capacitance. The technique involves measuring, as a function of pressure and temperature, the resonant frequency of an LC circuit in which the capacitor and core of the inductor constitute the sample.[6] This is quite different from the standard resonant circuit techniques for high-frequency dielectric constant measurement in which one measures directly the capacitive and resistive components of the sample capacitor (25).

A schematic diagram of one modification of the sample arrangement is shown in Fig.16. The sample material is prepared in the form of a right circular cylinder and two cuts are made parallel to its axis, as shown. The center slab is made into a thin parallel plate condenser by attaching thin metal-foil electrodes to its two large faces. Enough material is shaved off these faces to compensate for the thickness of the electrodes. The three sections of the sample are reassembled, and a wire coil is wound on the resulting cylindrical core, Fig.16. The ends of the coil are connected, one each, to the electrodes (or plates) of the condenser. What we have then is a series LC circuit with the coil as the inductive element and the condenser as the capacitive element. The resonant frequency of such a circuit is given by:

$$f_r = \frac{1}{2\pi} (LC)^{-\frac{1}{2}} \tag{7}$$

A pick-up coil is wound around this LC cir-

[6] The technique was conceived by E.H. Poindexter of these Laboratories.