Title
PYROELECTRIC CERAMICS AS DETECTORS OF FAST ATOMIC BEAMS

Permalink
https://escholarship.org/uc/item/58k7z8qp

Authors
Berkner, Klaus H.
Myers, Booth R.
Pyle, Robert V.

Publication Date
1968-03-21

UCRL-18021

University of California

Ernest O. Lawrence Radiation Laboratory

PYROELECTRIC CERAMICS AS DETECTORS OF FAST ATOMIC BEAMS

Klaus H. Berkner, Booth R. Myers, and Robert V. Pyle

March 21, 1968

Submitted to
Review of Scientific Instruments

UCRL-18021
Preprint

UNIVERSITY OF CALIFORNIA

Lawrence Radiation Laboratory
Berkeley, California

AEC Contract No. W-7405-eng-48

PYROELECTRIC CERAMICS AS DETECTORS OF FAST ATOMIC BEAMS

Klaus H. Berkner, Booth R. Myers, and Robert V. Pyle

March 21, 1968

UCRL-18021

PYROELECTRIC CERAMICS AS DETECTORS OF FAST ATOMIC BEAMS*

Klaus H. Berkner, Booth R. Myers,† and Robert V. Pyle

Lawrence Radiation Laboratory
University of California
Berkeley, California

March 21, 1968

ABSTRACT

A method for detecting fluxes of energetic atoms with pyroelectric ceramics is described. The detector consists of a commerically available, polarized lead zirconate-lead titanate (or barium titanate) disk which is silvered on both sides to provide electrical contact. The atoms are stopped in one of the silvered surfaces, and the resulting change in temperature gives rise to a pyroelectric signal. In our application the atomic beam is chopped, and the signal-to-noise ratio is increased by phase-sensitive amplification. Our detectors have been calibrated from 1.6×10^{-7} to 3×10^{-1} watt, and are remarkably linear over this range.

Atomic collision experiments often require quantitative measurements of fluxes of energetic atoms. When the fluxes are too high for particle counting techniques to be applicable, detectors commonly used measure electron currents emitted from bombarded surfaces, light emitted from scintillators, temperature rise in thin foils (with thermocouples or thermistors), or currents arising from ionization in gas cells or thin foils. In this note we describe a detection method that utilizes the pyroelectric effect.

The detector consists of a polarized lead zirconate—lead titanate (or barium titanate) ceramic disk which is silvered on both sides to provide electrical contacts. The atoms are stopped in one of the silvered surfaces and the resulting change in temperature causes a change in the polarization, which induces a potential difference across the two surfaces. In our application the beam is chopped and an alternating signal is obtained. This simplifies amplification and interpretation of the signal and allows us to increase our signal-to-noise ratio by measuring the signal with a phase-sensitive amplifier.

Among the desirable properties of a detector are long-term stability, fast time response, good sensitivity, wide dynamic range, and insensitivity to surface contamination, radiation damage, beam diameter, and beam position. Detectors that make use of the pyroelectric effect appear to satisfy most of these requirements.

A number of papers on the suitability of pyroelectric crystals as thermal detectors, principally of electromagnetic radiation, have appeared in the literature in recent years; articles by Cooper[1] and by Hadni et al.[2] give good summaries of the principles and possibilities. We do not know of any published applications to atomic beam monitoring, although Barnett and Ray[3] have measured pyroelectric currents due to steady-state beams, and Barnett and co-workers[4] and Nexsen[5] have investigated pyroelectric detection of fast pulses of neutral atoms from controlled fusion experiments. The chopped-beam technique described below has been used continuously and successfully for approximately 2 years to measure equivalent currents of about 10^{-10} to 10^{-6} ampere at power levels in the range 10^{-6} to 10^{-1} watt.

Commercially available[6] 1-in.-diameter ceramic disks of barium titanate and lead zirconate-lead titanate in thicknesses of 0.010 to 0.10 in. are mounted in the holder shown schematically in Fig. 1. The disks come with thin (0.0003 to 0.001 in.) silver coatings on each side; these coatings are sufficiently deep for our experiments with 5- to 50-keV deuterons, but at high energies the conducting layer on the beam side should be thickened sufficiently to stop the particles in the metal.[7] The beam side of the disk is in electrical contact with a copper cylinder, and a lead is brought out so that the system can be used as a Faraday cup; this lead is shorted to ground during measurements of the pyroelectric signal. The pyroelectric signal is obtained from a spring-loaded contact to the back surface of the disk. The internal structure is supported by a vacuum-tight ceramic feed-through seal, and the whole assembly is attached to the accelerator vacuum system by a nonconducting sleeve to avoid multiple grounds. At lower levels above about 10^{-3} watt the signal could be amplified and used directly. Below this power level we have problems with acoustical and electrical noise, and therefore routinely use phase-sensitive detection.

The experimental arrangement is shown in Fig. 2. The accelerator beam of known energy is chopped, and the charged and neutral components emerging from a gaseous or solid target (not shown in Fig. 2) are electrostatically separated. The modulated signal from the pyroelectric ceramic passes through a preamplifier and then into a phase-sensitive amplifier.[8] The output of the phase-sensitive amplifier is monitored with an oscilloscope, displayed on a current meter, and integrated.

The neutral detection system is calibrated by switching the charged component from the accelerator onto the pyroelectric disk. As this is easily done many times during an actual experiment, the usefulness of the device does not require a constant proportionality between input power and output signal. However, the device is remarkable linear in the range in which we have calibrated it, which covers more than six orders of magnitude (Fig. 3). We have not attempted to calibrate at power levels above 300 milliwatts or below about 100 nanowatts, but noise of as yet undetermined origin limits the usefulness below 150 nW with the integration times that we commonly use, 3 sec or less.

The dependence of the detection sensitivity on the fraction of the area of the detector that was illuminated was checked in an auxiliary experiment: The surface of a disk was blackened to make the absorption uniform and a chopped light beam from a distant source was initially focused on the detector. By moving the detector away from the focal point, the area of illumination could be varied while constant power was maintained. Within the 10% uncertainties of the experiment, the signal was constant, i.e., independent of the illuminated area.

The dependence of the detection efficiency on the position where a small-diameter beam hit was checked by sweeping a 0.03 -in.-diameter proton beam across the disk surfaces. These signals were independent of position to within about 5%.[9]

Although a complete analysis of the response of the detector must be very complex because of such things as edge effects and the variation of the pyroelectric coefficient with temperature, analysis of the type given in Ref. 2 shows that the amplitude of the signal should vary as

$$V \approx P \frac{pA}{4\pi mCc} \frac{f}{\left[(f^2 + f_T^2)(f^2 + f_e^2)\right]^{1/2}} \text{ volts,}$$

where P is the power (watts) incident on a disk of area A (m^2) at the chopping frequency f (Hz), p is the pyroelectric coefficient (coulombs $^\circ C^{-1}\ m^{-2}$), m is the mass (kg) of the ceramic disk, C is the electrical capacitance (farads) of the detector-preamplifer circuit, c is the heat capacity per unit mass (joules $^\circ C^{-1}\ kg^{-1}$), $2\pi f_T = 1/\tau_T$, where τ_T is the thermal time constant of the disk in its mounting, and $2\pi f_e = 1/\tau_e$, where τ_e is the electrical time constant of the circuit. The quantity $pA/4\pi mCc$ is approximately 2.5 volts/joule for one of our typical ceramics.

Differentiation of the above equation shows that the maximum signal is obtained at a frequency $f_{max} = (f_e f_T)^{1/2}$. The calculated value of f_e for our circuit is about 1 sec^{-1}, and the value of f_T (measured by applying a thermal pulse to the disk and measuring the decay of the pyroelectric signal) is typically 3 sec^{-1}. Thus $f_{max} \approx 1.7$ Hz.

Measured values of signal vs. frequency were obtained for $2 < f < 40$ Hz, and were found to drop off with increasing frequency as predicted. For convenience in tuning and monitoring the beam, we prefer to operate at a frequency higher than f_{max}, namely about 10.5 Hz. The data shown in Fig. 3 are in good agreement with the predictions of the theoretical expression.

The results obtained from different samples showed that although there were factor-of-two variations among specimens, there was no particular choice between barium titanate (curie point 130°C) or lead zirconate-lead titanate (curie point 260°C) in our experiments. This might not be true in other applications because the pyroelectric coefficient is a function of temperature. In our experiments the results were also approximately independent of crystal thickness.

In summary, for situations commonly encountered in atomic cross-section experiments, pyroelectric ceramics can be used to make rugged and sensitive neutral-beam detectors. The useful signal might be increased by adjusting the mean operating temperature by external means, or by using single crystals instead of ceramics or, perhaps, other compounds.

We thank Dr. C. M. Van Atta for encouraging this research, Dr. S. B. Lang and Dr. W. Nexsen, Jr., for useful comments on pyroelectric detectors, Mr. V. J. Honey and Mr. P. D. Smith for valuable advice and aid with the electronics, and Mr. J. W. Stearns for his participation in various experiments.

REFERENCES

*Work done under the auspices of the U. S. Atomic Energy Commission.

†Summer employee at LRL.

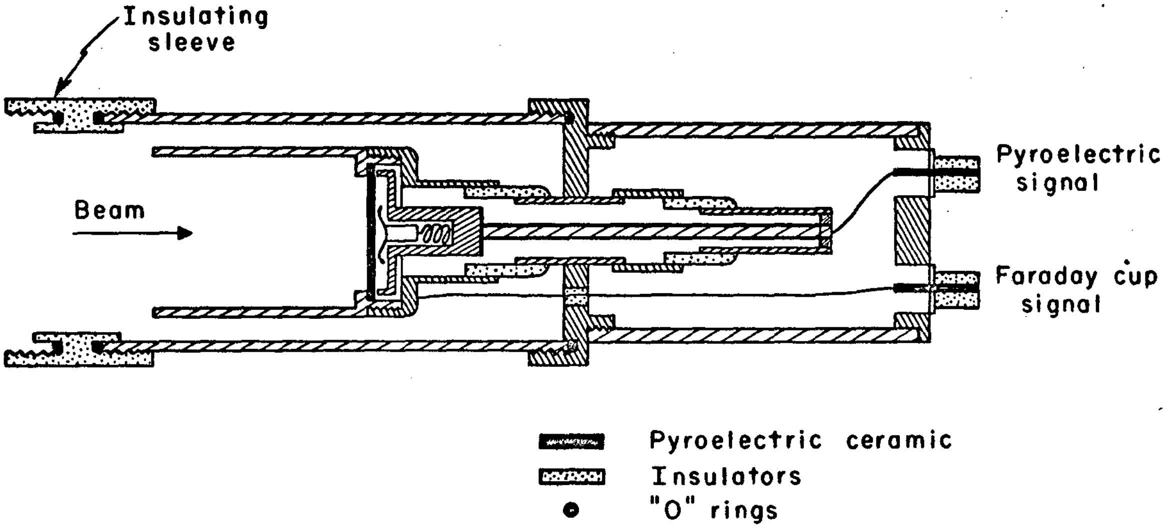
1. J. Cooper, Rev. Sci. Instr. 33, 92 (1962); J. Sci. Inst. 39, 467 (1962).
2. A. Hadni, Y. Henninger, R. Thomas, P. Vergnat, and B. Wyncke, J. Phys. (Paris) 26, 345 (1965).
3. C. F. Barnett and J. A. Ray, ORNL-3836, 1965, p. 71 (unpublished);
4. C. F. Barnett, D. A. Griffen, M. O. Krause, and J. A. Ray, ORNL-3908, 1965, p. 96 (unpublished).
5. William Nexsen, Jr. (LRL, Livermore), private communication.
6. The disks of barium titanate (Glennite HS-21) and lead zirconate—lead titanate (Glennite HST-41) were purchased from Gulton Industries, Metuchin, N. J.
7. We have had two disks fail. In one case there was a fracture in the ceramic, in the other the silver coating was penetrated by the beam. Erratic signals were observed in both cases.
8. Princeton Applied Research Corp., Princeton, N. J., type HR-8 lock-in amplifer with type A preamplifier.
9. G. A. Burdick, R. T. Arnold, and T. G. Hickman, J. Appl. Phys. 37, 4287 (1966), observed large variations in sensitivity over the surface of a $BaTiO_3$ disk, using a 1-mm-diameter laser beam of unspecified intensity.

FIGURE LEGENDS

Fig. 1. Schematic cross section of pyroelectric detector.

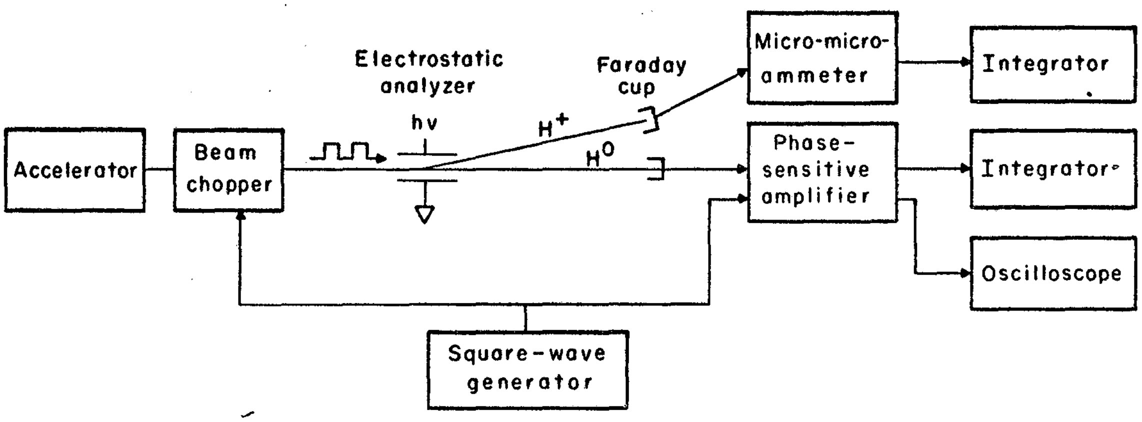
Fig. 2. The experimental arrangement.

Fig. 3. Output signal vs. power input. These data were taken at a chopping frequency of 10.5 Hz. Representative uncertainties at several power levels are shown.



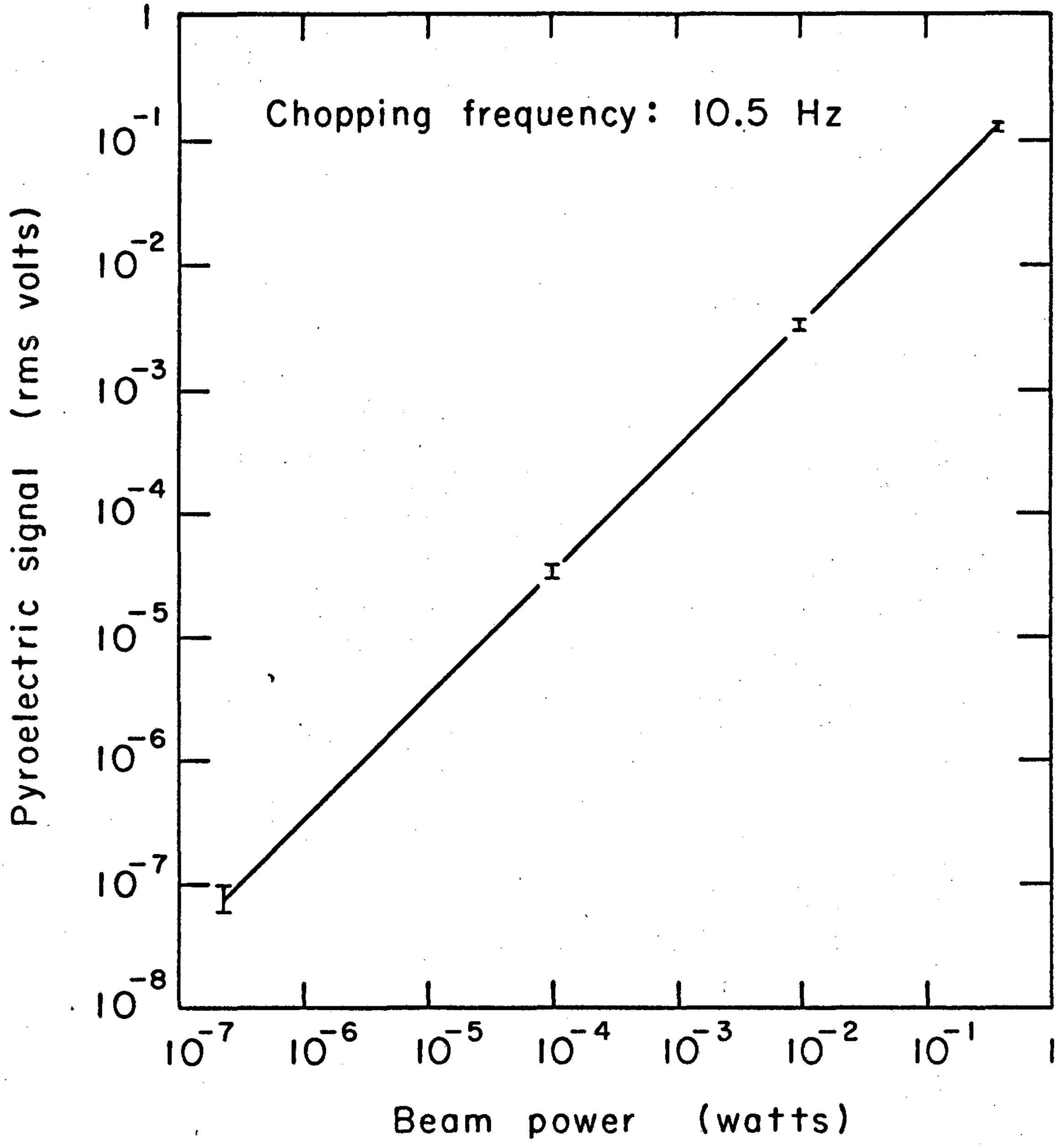
XBL683-2123

Fig. 1



XBL683-2124

Fig. 2



XBL683-2125

Fig. 3