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ABSTRACT

In order to build a thin particle detector with 10 micron spatial resolution and automatic readout, the avalanche of ionization electrons in high electric fields in liquid argon and liquid xenon has been studied. We present a scheme using an array of points that could be used to make a reliable liquid argon filled detector. The avalanche pulses in liquid xenon have a rise time more than three orders of magnitude faster than that in liquid argon, suggesting that the positive charge carriers are holes, and making possible a detector with a time resolution of better than 100 nanoseconds. A direct observation of hole conduction is described.

We have been studying the avalanche of ionization electrons in high electric fields in the noble liquids, argon and xenon. We have observed the avalanche in both of these liquids[1, 2] at fields of about 10^6 volts/cm. We believe the existence of this avalanche makes possible a particle detector with a thickness of 100 microns or less, with a spatial resolution of ± 10 microns. Such a detector would introduce <0.005 radiation lengths. Four our studies, we have constructed detectors using single wires 2.5 to 20 microns in diameter, filled with purified [1, 2] liquid argon and xenon in a geiger counter geometry.

We have been unable to make a reliable detector using liquid argon. The efficiency for particle detection has never been better than about 20%. The low efficiency is due to the existence of "hot spots" on the wire, smaller than 4 mm in length. The wire has approximately 100% efficiency for avalanche in the region of these hot spots, and almost zero efficiency elsewhere. The hot spots may be due to sub-microscopic irregularities that locally increase the field strength. We have been unable to control the number of hot spots that occur on a wire submerged in liquid argon. If we attempt to improve the efficiency by increasing the voltage, we observe spontaneous sparkling independent of the presence of ionizing radiation. However we have observed that a hot spot always occurs on the tip of an etched tungsten point, if the tip radius is one micron or less. It should therefore be possible to construct a useful liquid argon particle detector by using an array of sharp points. Arrays of such points have been made with 25 micron spacing by Done Cone and his group at the Stanford Research Institute using a vapor deposition technique. A typical array is shown in figures 1 and 2.

Our efforts with liquid xenon have been much more successful. With a 3.5 micron diameter tungsten wire, submerged in purified liquid xenon,[3] typical operation is as follows. At low voltages, below about -500 volts (voltage of a concentric cylindrical cathode about 4 mm in radius with respect to the wire) we observe only ionization charges collected on the wire. Between -500 V and -3.5 KV the ionization electrons avalanche in the vicinity of the wire, giving a gain of up to 10^4. But unlike our results with argon the efficiency for avalanche is good all along the wire, somewhere between 25% and 100%. At higher voltages we have observed a sparking mode, with the chamber operating as a D-C spark Chamber. However the efficiency of the chamber in this mode is very low, probably less than 1%. The spark does not seem to damage the fine wire. A hundred volts or so above the D-C spark chamber voltage the sparks occur spontaneously, in the absence of ionizing radiation. Because of the larger pulses in the spark mode, we are attempting to improve the efficiency of our detector by pulsing it to higher voltages. We know that our chambers can be pulsed to greater than 10 KV for 1 μs without spontaneous sparking, even when the D-C breakdown voltage is only 5 KV.

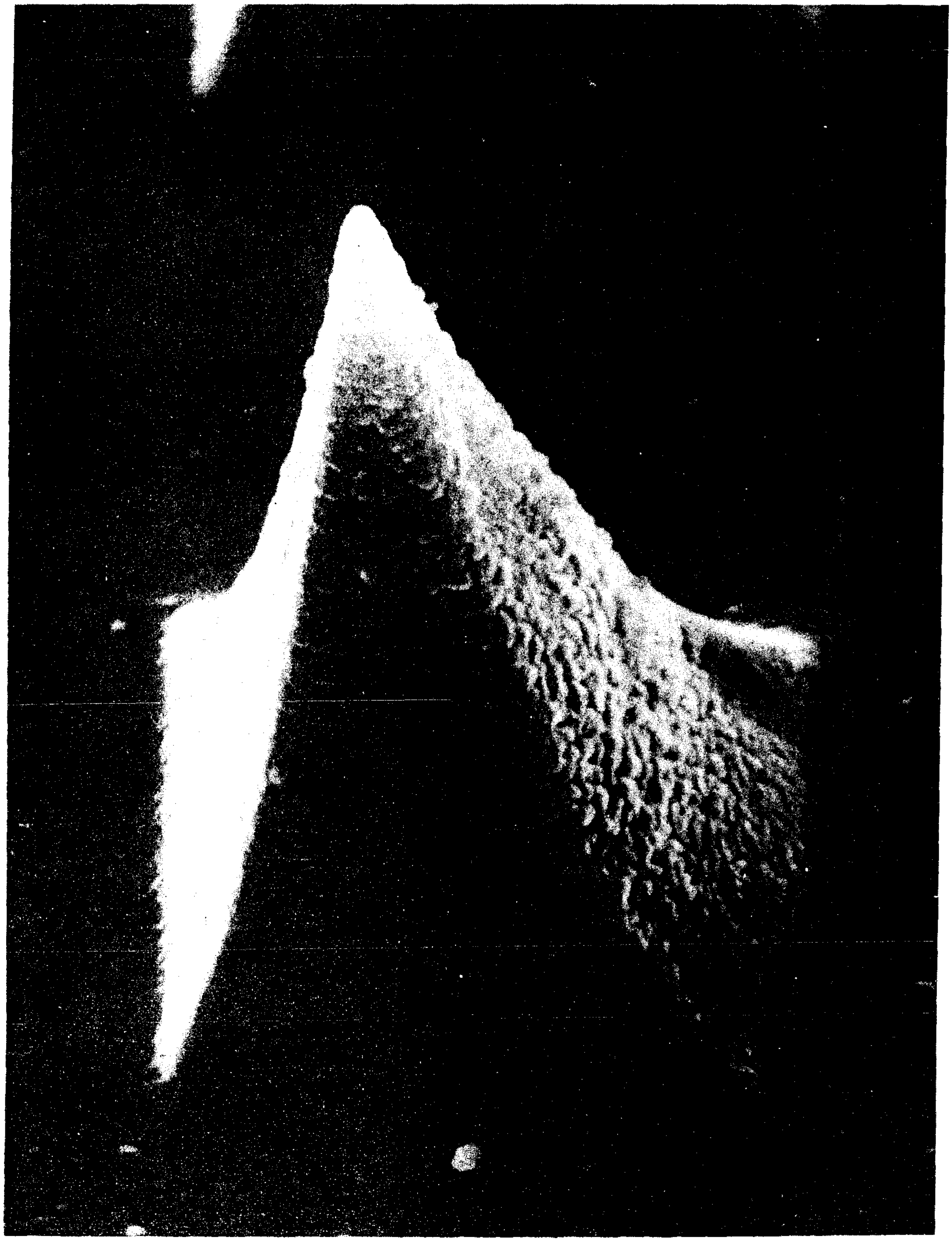

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Fig. 1. A pyramid made by Don Cone and his group at Stanford Research Institute. (Scanning electron microscope photograph.) The height of the pyramid is about 15 microns, and the material is an alumina-tungsten alloy.

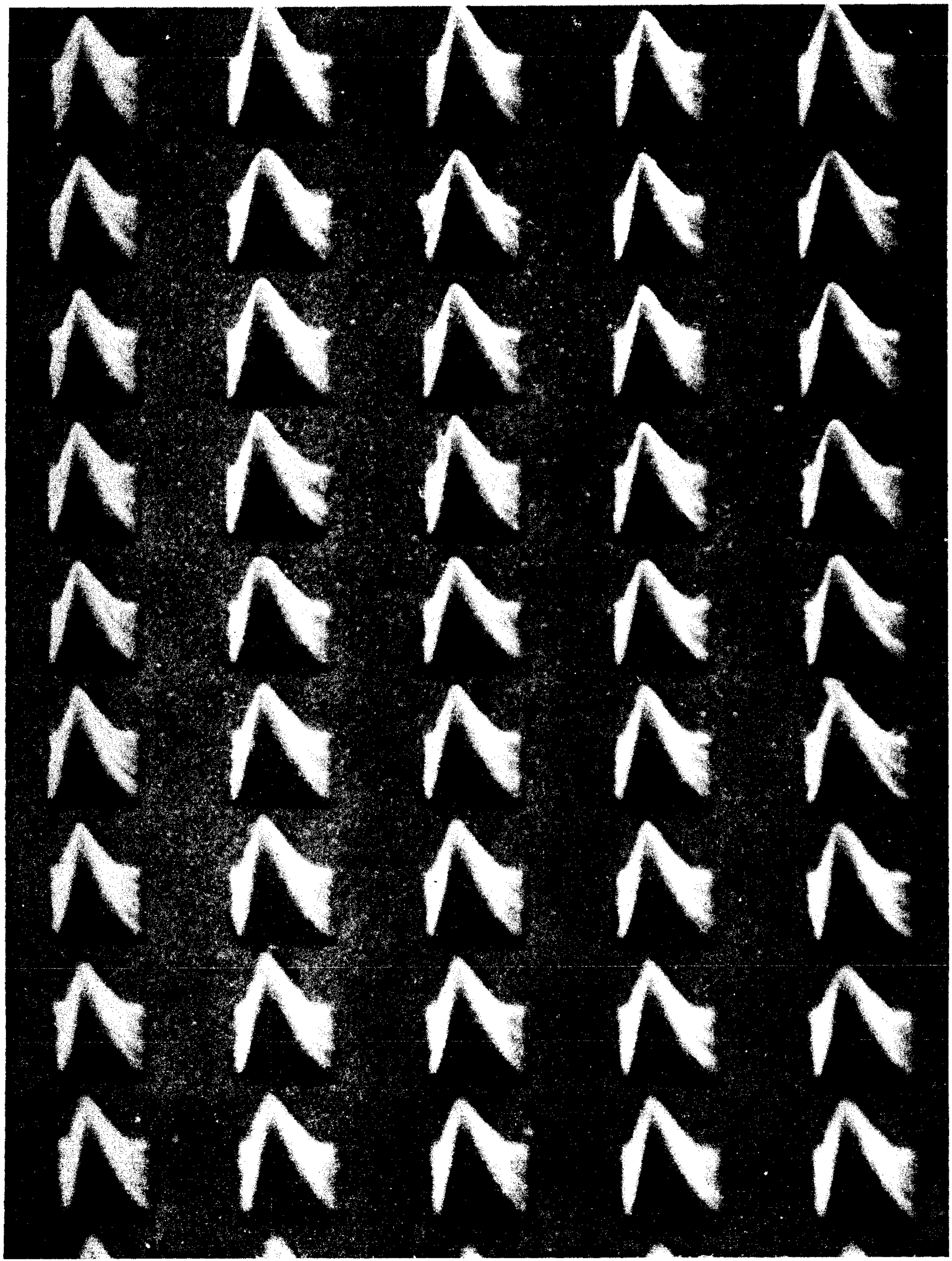

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Fig. 2. An array of pyramids. The spacing between tips is 25 microns.

The avalanche pulses in liquid xenon have one extremely interesting feature. Whether the avalanche occurs on a fine wire or an etched tungsten point, the rise-time is very fast, less than 6 nanoseconds, our measurement limited by the rise-time of our oscilloscope. For argon the rise-time is more than three orders of magnitude longer. The rise-time in our counters is determined by the motion of positive charges away from the wire, since most of the avalanche is created in the vicinity of the wire and the electrons move only a short distance to the anode. The fast rise time therefore indicates high positive charge mobility, suggesting that the positive charge carriers are holes.

We have done one other experiment that suggests that hole conduction occurs in purified liquid xenon under the influence of high electric fields. We constructed a chamber with two spherical electrodes 3/16 inches in diameter, spaced 0.05 inches apart. On the lower sphere we placed a small Am^{241} alpha emitter. The range of the 5.5 MeV alphas is about 0.002 inches in both liquid argon and liquid xenon. Therefore the ionization occurs in the vicinity of the lower electrode. If the lower electrode is at negative voltage we observe the motion of the negative charges towards the upper electrode, and if the lower electrode is positive we observe the motion of positive charges. At 15 KV, in liquid argon, the drift time for the negative charges is less than 0.5 microseconds, and the drift time for the positive charges is greater than 50 microseconds, consistent with previous observations [4, 5, 6] that the negative carries are electrons and the positive carriers are ions. Using the same chamber filled with liquid xenon we find that the drift time for both positive and negative charges is less than 0.5 microseconds, indicating both electron and hole conduction.

The pulse height when the positive charge motion was observed was only 30% - 50% that for the electron motion, perhaps indicating that holes are more easily trapped on the impurities in our xenon than are electrons.

The fast rise time of the pulses in liquid xenon has important consequences for high energy physics experiments. It should allow the design of a detector with good time resolution (20-40 nanoseconds) as well as good spatial resolution, using the convenient scanned readout described in references 7 and 8.

For the details of some of the experiments described in this paper we refer the reader to reference 2.

We would like to thank Dennis B. Smith and Carl Pennypacker for help in all aspects of this work, and we are grateful to Charles Kittel for a very informative conversation. We are indebted to Buck Buckingham, Ernie Currier, Joe Savignano, and Tony Vuletich for help in the construction and maintenance of our apparatus.

FOOTNOTES AND REFERENCES

1. Prospect of High Spatial Resolution for Counter Experiments: A New Particle Detector Using Electron Multiplication in Liquid Argon. Derenzo, Muller, Smits, Alvarez, UCRL-19254. Published in 1969 NAL Summer Study Reports, Aspen, Colorado.
2. Recent Developments in High Resolution Noble Liquid Counters. Derenzo, Smits, Zaklad, Alvarez, and Muller. UCRL-20118. To be published in the 1970 NAL Summer Study Report.
3. We have purified our xenon using a purifier similar to that used for argon, described in reference 2. We have not measured the amount of residual impurities, although we know that when purifying argon the amount of residual oxygen is less than 200 parts per million.
4. G. W. Hutchinson, Nature 162, 610 (1948); thesis, St. Johns College, Cambridge, 1951 (unpublished).
5. Davidson and Larsh, Phys. Rev., 74, 220 (1948); 77, 706 (1950).
6. John Marshall, Rev. Sci. Inst. 25, 232 (1954).
7. In principle, a liquid argon detector also has good time resolution because although the rise-time is determined by the mobility of positive charges, the delay between the passage of an ionizing particle and rise of a pulse to a certain height is determined by the electron velocity. Thus although the pulse is slow,

it reaches a certain pulse height at a well determined time.

8. For a detailed discussion of the readout methods applicable to the high resolution chambers discussed here, see Integrated Circuit Readout for Closely Spaced Wire Arrays, Haim Zaklad, NAL 1970 Summer Study Report SS-181, also UCRL-20123.