MEASURING THE PRE-ARCING TEMPERATURE OF HIGH-BREAKING-CAPACITY FUSELINKS BY THERMAL IMAGING

*A.F. Howe, D. de Cogan
+P.W. Webb
†N.P.M. Nurse

SUMMARY The paper describes experiments to measure by thermography the variation in temperature across the surface of fuse elements carrying up to rated current.

1. INTRODUCTION To ensure that fuselinks do not deteriorate when they carry continuously rated current, manufacturers design their elements in such a way that the notch temperatures never reach values where permanent deformation of the element will normally occur. This sets a limit on the notch temperature for semiconductor fuselinks with silver elements at about 250°C and for industrial fuselinks with copper elements around 140°C. There is no easy method to measure these temperatures directly. For example, the use of thermocouples to measure notch temperatures is inappropriate because the masses of notches are so small that heat would be conducted away from the restrictions along the thermocouple wires. Instead, notch temperatures have to be deduced from the measurement of the "hot" fuse resistance and computations based on Fourier's Law [1],[2]. This paper describes a feasibility study to investigate whether a technique called thermography might be used to measure the temperatures of the restrictions in fuse elements.

2. THERMOGRAPHY Thermography is widely used in industrial and medical applications. In this instance a system is being developed to measure the surface temperatures of samples [3]. The operation of the system relies on all black bodies radiating energy which is proportional to the absolute temperature to the fourth power. This phenomenon is called Stefan's Law and is written mathematically thus:

$$\text{Radiated Energy} = \sigma T^4$$

where σ = Stefan-Boltzmann constant = $5{\cdot}67 \times 10^{-8}\ \mathrm{Jm^{-2}\ s^{-1}\ K^{-4}}$, and

T = absolute temperature

For temperatures below approximately 400 to 500°C the emitted radiation is almost entirely within the infra-red spectrum. To measure this radiation experimenters use a scanning thermal (infra-red) imager

---

*University of Nottingham, U.K.
+University of Birmingham, U.K.
†Brush Fusegear Limited, U.K.

like the Barns RM50 (see Fig. 1) or a fixed position infra-red microscope, like the Barns RM2A in conjunction with a moveable sample table (see Fig. 2) [3]. The instruments which are fitted with liquid-nitrogen cooled indium-antimonide (InSb) detectors, are focussed on a small region of the specimen surface (35 μm, 17 μm or 7 μm diameter) and a measurement is taken. .035 mm Adjustments are then made to the scanning mirrors in the thermal imager, or the position of the moveable sample table relative to the position of the fixed microscope, to obtain a measurement from an adjacent area. The process continues until the whole surface has been examined. The scanning is automated and the measurement signals are transmitted to a PDP 11/34A computer where they are digitised, converted to temperatures and stored [3]. Quantising the results enables an image, which shows the variations in temperatures across the surface, to be displayed on a cathode ray tube.

3. MEASUREMENTS WITH "GREY" SAMPLES

"Grey" bodies emit lower radiation than black bodies at the same temperature, and so Stefan's Law is modified for "grey" bodies thus

Radiated energy = $\varepsilon \sigma T^4$

where ε = emissivity, which has a value between 0 and 1.

Before thermography can be used to find the surface temperature of a "grey" body the experimenter must know the emissivity or make it unity by some artificial means. If the former is adopted then the sample is heated to known temperatures and the emission is observed. This information is supplied as data to the computer, which then applies software corrections to the data derived during the thermographic measurements of the samples.

4. INVESTIGATIONS WITH FUSE ELEMENT PROFILES

Using thermography in its present state of development it is not possible to scan the notch region of a fuse element mounted in a ceramic body and embedded in sand. So for the investigationary tests specimens were made by evaporating silver films on to clear quartz discs. The profiles were similar to a semiconductor fuselink element currently produced by Brush Fusegear Limited.

The emissivity of silver is less than unity. In order to save the time involved in calibrating the emissivity the fuse element was coated with a thin layer of carbon black, which has an emissivity of 1·0. Independent measurements showed that this had little effect on the electrical properties of the fuse element.

4.1 Steady-state Direct Current Test

In the first test with the fuse element profile a current of 2A d.c. was passed through the element for several minutes to allow a steady-state temperature distribution to be established within the element. The measurements were then taken and the temperature variations were displayed on a cathode ray tube, as shown in Fig. 3. When a colour monitor is available the regions of intermediate temperatures are shown in different colours to improve the clarity of the display.

The computer stores the temperature for each small region in the surface as a discrete value so it is possible to produce

a) temperature profiles along (line A) and across (line B) the narrow part of the element (see Figs. 4 and 5),

b) "close-ups" of the temperature distribution in a small part of the fuselink profile. If this option is selected then the temperature scale is automatically adjusted to shade the hottest points in the chosen area black, the coldest points white and redistribute the grey divisions accordingly. With this facility it is possible to examine closely any irregularities in the temperature pattern.

c) Three-dimensional representations of the temperature profile, as illustrated in Fig. 6.

To test the accuracy of the measurements the temperature distribution for the fuse element was calculated using the finite-difference method developed by Leach et al [2] (see Fig. 7). Comparison of the isotherms with Fig. 3 will show that there was reasonable agreement between the two methods. One reason for the small discrepancy in the notch region is that the computational method ignored the fact that with the fuse element firmly attached to the quartz glass disc some heat will be conducted from the fuse restriction to the substrate.

4.2 Tests with alternating current

4.2.1 Measurements taken at one point The fixed staring microscope, Barns RM2A, is used in conjunction with the moveable table for these measurements. The instrument records the temperature measurements at set times at a chosen location on the surface of the specimen. The results can be plotted on a transient recorder or sent to the computer for analysis, as shown in Fig. 2. Fig. 8 shows the variation in temperature when an alternating current flows through the fuse element when it is mounted on quartz. This technique can also be used to monitor thermal transients. Fig. 9 shows how the temperature at a discrete point increases during the first few cycles of an alternating current.

4.2.2. Temperature variation over the whole surface To use the thermal imager to measure the temperature variations in the elements when a steady-state alternating current flows through it, the instrument with the scanning mirrors is used. The instrument is focussed on a small area of the specimen. Then at a chosen instant on the voltage waveform, say t ms after a voltage zero, a measurement is taken. The scanning mirrors are then adjusted to look at the adjacent point on the surface and at t ms after the next voltage zero the second measurement is taken. The process continues until the whole of the fuse element has been examined. The timing of the "firing" pulse is illustrated simply by Fig. 10.

The gating delay is selectable so a "family" of thermal plots can be produced to demonstrate how the temperature fluctuates across the whole surface as the current varies with time (see Fig. 11).

5. FUTURE WORK For thermographic measurements of fuse element temperatures to have practical significance the elements must be covered by granular quartz. However, it is impossible to "look" through grains so the next step is to modify the test rig (as illustrated in Fig. 12)

to take measurements through the quartz. Unfortunately, the temperatures measured will not be the element temperatures, but some function of the correct values. As a result software is now being developed so that the measurements from the second phase of the work can be presented in a meaningful way.

It is hoped that the results from the proposed work will prove useful to fuse designers and will aid the future development of fuse element designs.

6. ACKNOWLEDGMENTS The authors wish to thank Mr. I.R. Shelton, the Universities of Birmingham and Nottingham, and Brush Fusegear Limited for the facilities provided.

7. REFERENCES

1. Wright, A. and Newbery, P.G., Electric Fuses, (Peter Peregrinus, 1982).

2. Leach, J.G., Newbery, P.G. and Wright, A., "Analysis of high-rupturing-capacity fuselink pre-arcing phenomena by a finite-difference method", Proc. IEE 120 (9), 1973, pp. 987-993.

3. Webb, P.W., "Measurement of thermal transients in semiconductor power devices and circuits", Proc. IEE, 130, Pt I, (4) pp. 153-159.

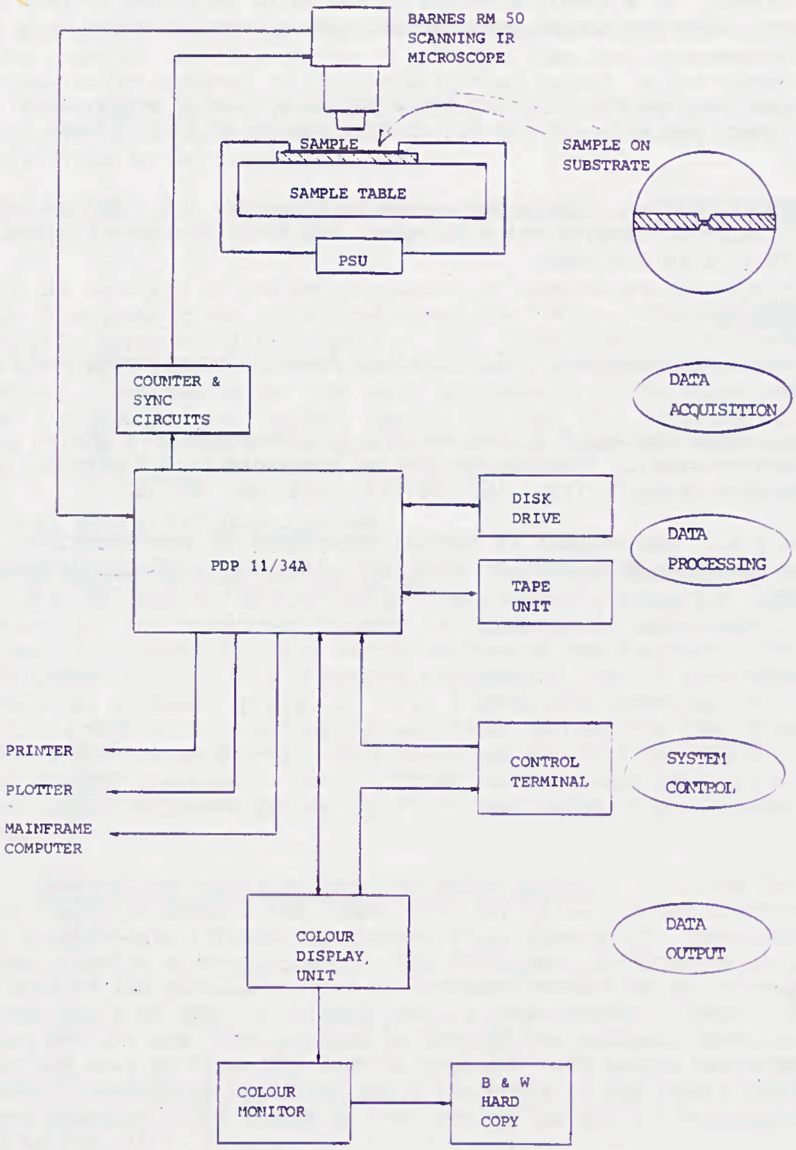

BARNES RM 50
SCANNING IR
MICROSCOPE
SAMPLE
SAMPLE ON
SUBSTRATE
SAMPLE TABLE
PSU
COUNTER &
SYNC
CIRCUITS
DATA
ACQUISITION
PDP 11/34A
DISK
DRIVE
TAPE
UNIT
DATA
PROCESSING
PRINTER
PLOTTER
MAINFRAME
COMPUTER
CONTROL
TERMINAL
SYSTEM
CONTROL
COLOUR
DISPLAY
UNIT
DATA
OUTPUT
COLOUR
MONITOR
B & W
HARD
COPY

Fig. 1

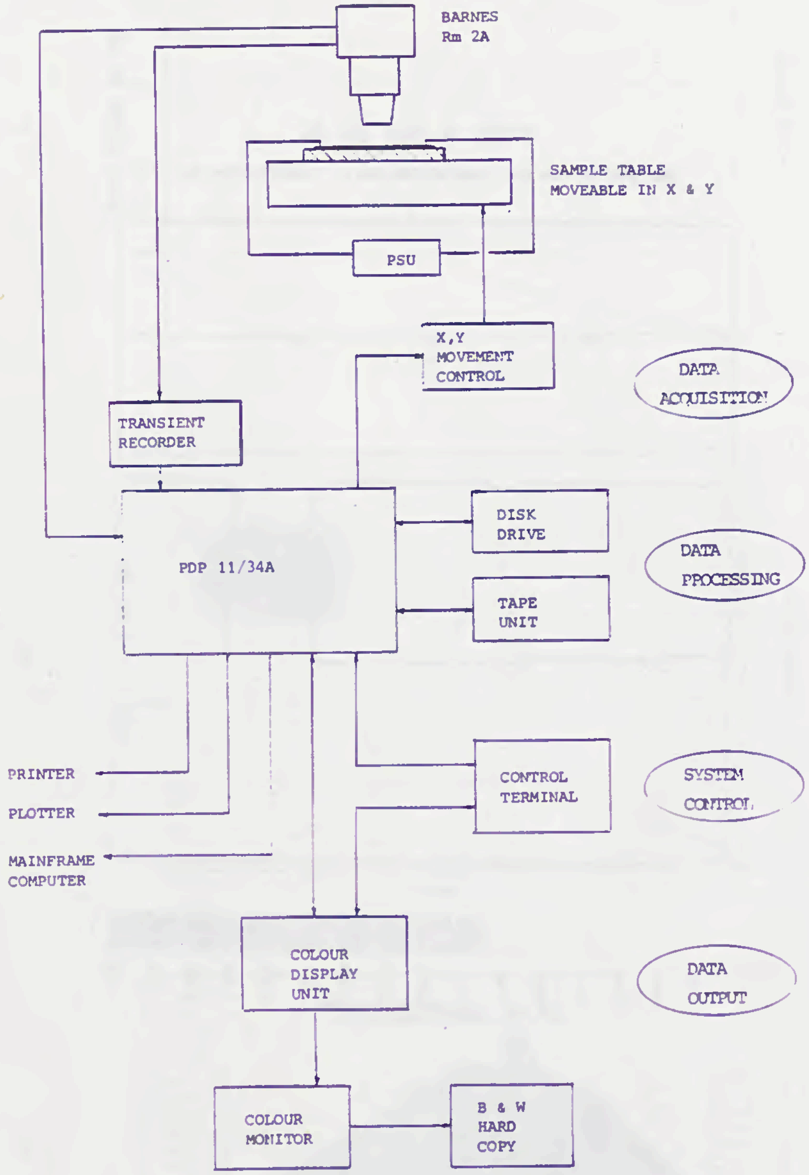

BARNES
Rm 2A
SAMPLE TABLE
MOVEABLE IN X & Y
PSU
X,Y
MOVEMENT
CONTROL
DATA
ACQUISITION
TRANSIENT
RECORDER
PDP 11/34A
DISK
DRIVE
TAPE
UNIT
DATA
PROCESSING
PRINTER
PLOTTER
MAINFRAME
COMPUTER
CONTROL
TERMINAL
SYSTEM
CONTROL
COLOUR
DISPLAY
UNIT
DATA
OUTPUT
COLOUR
MONITOR
B & W
HARD
COPY

Fig. 2

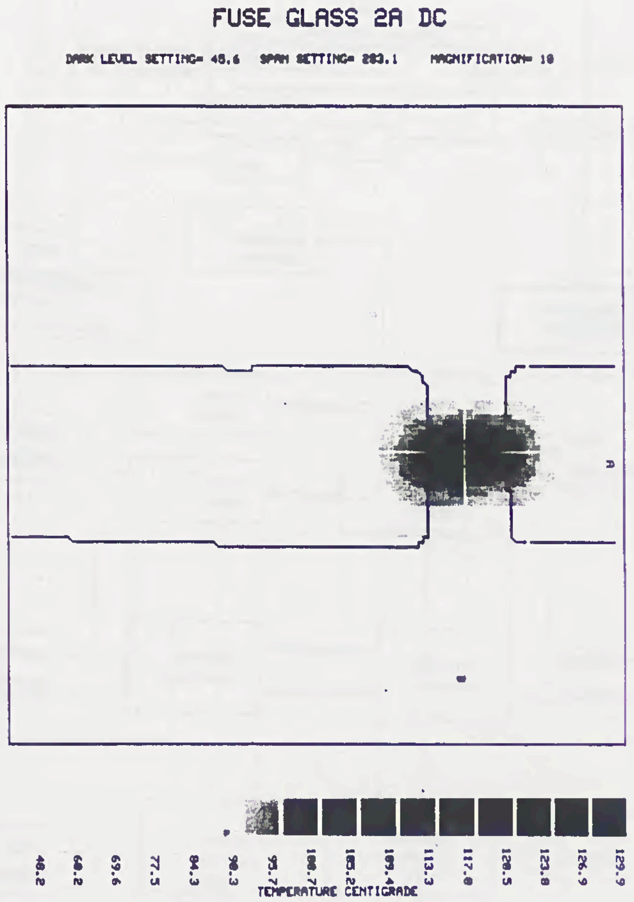

FUSE GLASS 2A DC
DARK LEVEL SETTING= 48.6   SPAN SETTING= 283.1   MAGNIFICATION= 10
A
48.2
60.2
69.6
77.5
84.3
90.3
95.7
100.7
105.2
109.4
113.3
117.0
120.5
123.8
126.9
129.9
TEMPERATURE CENTIGRADE

Fig. 3

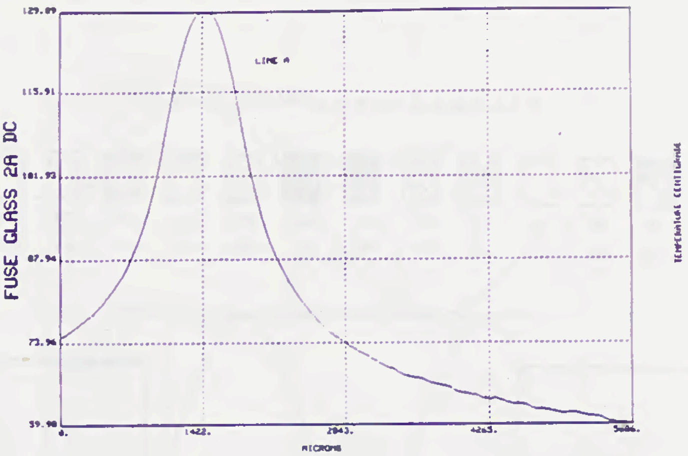


Fig. 4

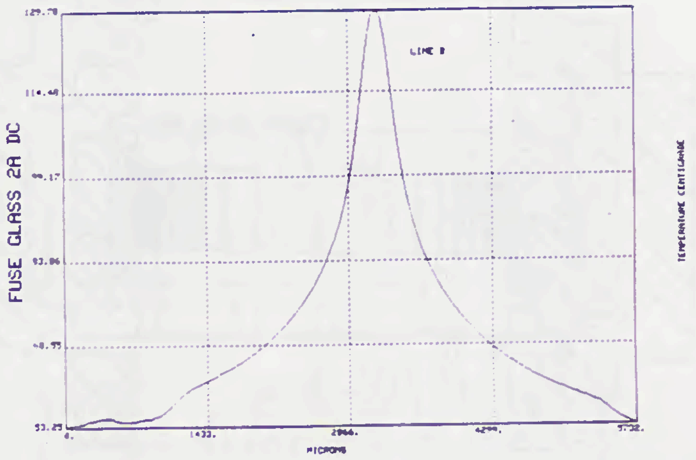


Fig. 5

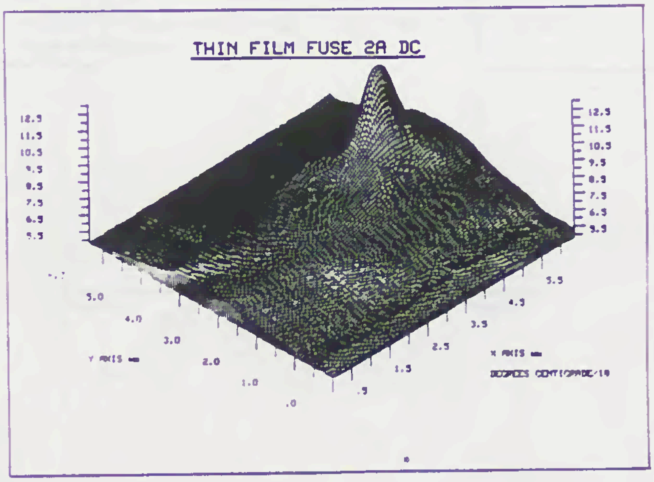


Fig. 6

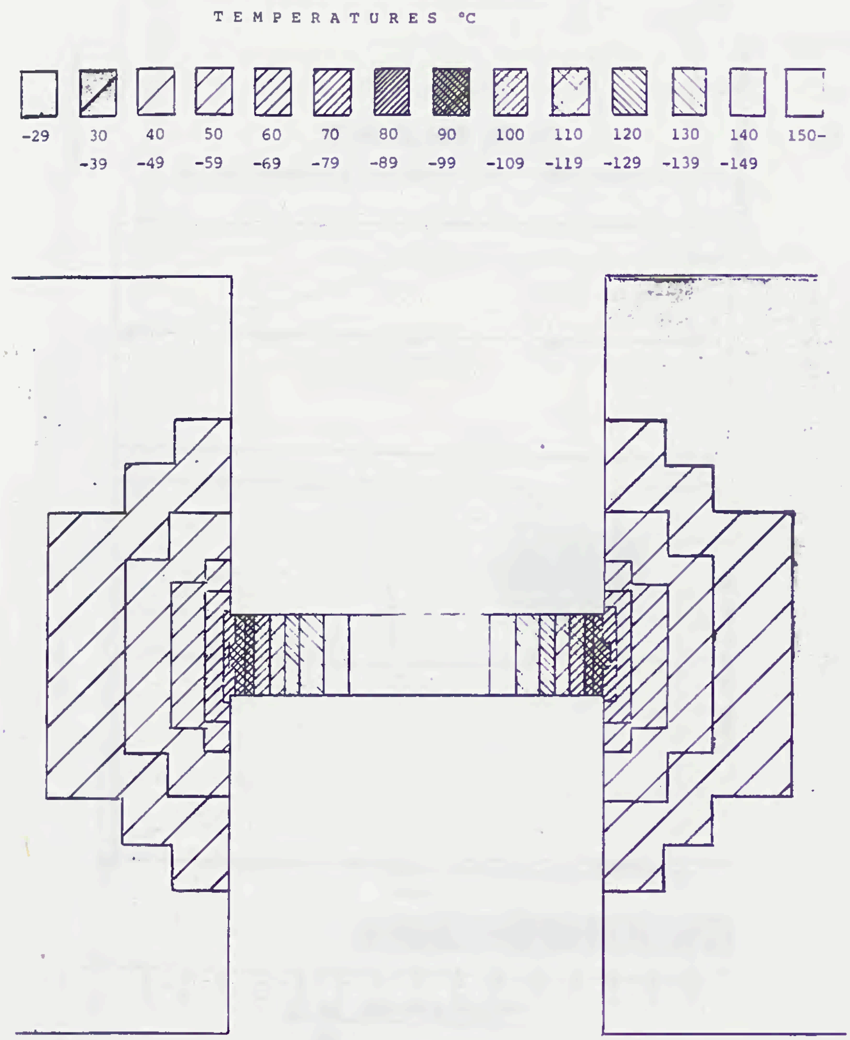

TEMPERATURES °C
-29
30 -39
40 -49
50 -59
60 -69
70 -79
80 -89
90 -99
100 -109
110 -119
120 -129
130 -139
140 -149
150-

Fig. 7

Fig. 8

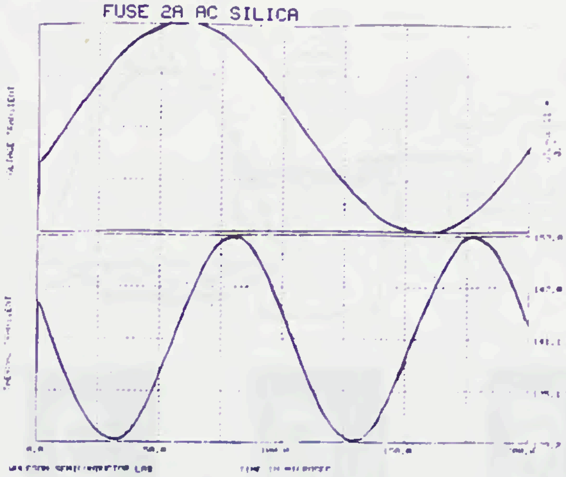


Fig. 9

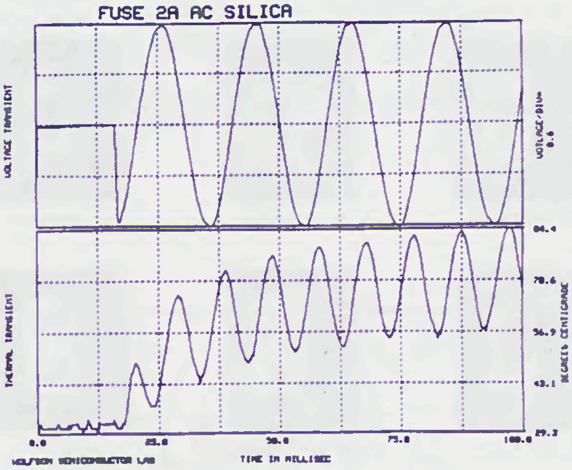
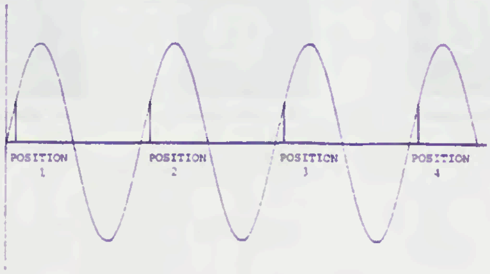
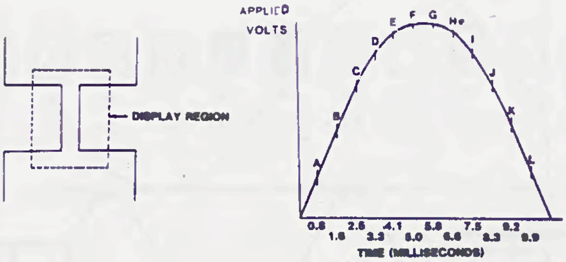


Fig. 10

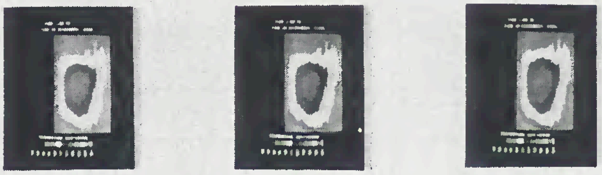




(A) AFTER 0.8 mS

(B) AFTER 1.6 mS

(C) AFTER 2.5 mS



(D) AFTER 3.3 mS

(E) AFTER 4.1 mS

(F) AFTER 5.0 mS

(G) AFTER 5.8 mS

(H) AFTER 6.6 mS

(I) AFTER 7.5 mS

(J) AFTER 8.3 mS

(K) AFTER 9.2 mS

(L) AFTER 9.9 mS

Fig. 11

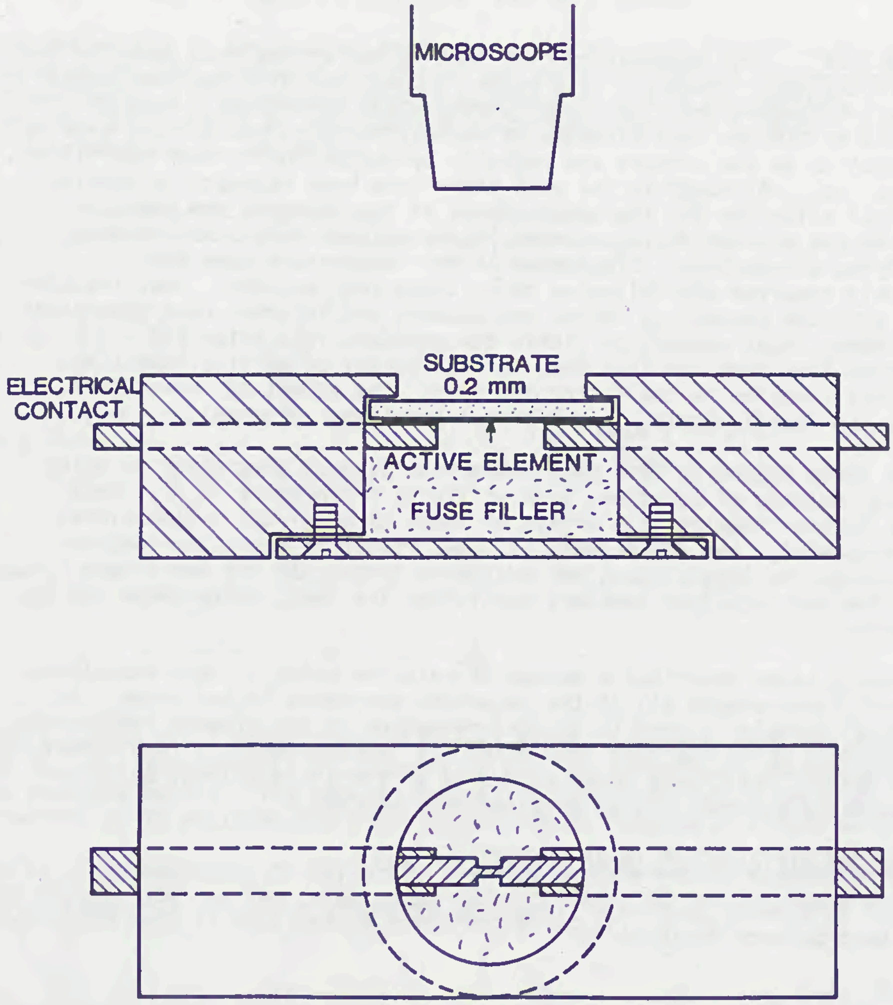

MICROSCOPE
SUBSTRATE
0.2 mm
ELECTRICAL
CONTACT
ACTIVE ELEMENT
FUSE FILLER

Fig. 12