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Pulsed Electron-Beam Heating

10 January 1969

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY
LINCOLN LABORATORY

PULSED ELECTRON-BEAM HEATING

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Group 24

TECHNICAL NOTE 1969-2

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ABSTRACT

A pulsed, 20 kv electron beam is focussed upon a vapor-deposited thermocouple, and the resulting temperature vs. time response is studied. The experimental data show much scatter, but are consistent with the theoretical prediction that the characteristic thermal response time τ is proportional to d^2 , where d is the beam diameter at the thermocouple. From these data, for the soft-glass substrate which was employed, if $d = 1\mu$, τ less than $1 \mu\text{sec}$ is predicted.

Accepted for the Air Force
Franklin C. Hudson
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I. INTRODUCTION

If heat is generated at the surface of a solid in a region of small area but negligible depth, thermal theory predicts^{1,2} that thermal equilibrium can be achieved in very short times. Specifically, the equilibrium time should be proportional to d^2 , where d is the diameter of the region, so that for $d = 1 \mu$, times less than 1 μ sec should be attainable. This theory is important in considerations of electron beam memories, where an electron beam focussed to a small spot is called upon to heat a small-diameter bit to a high temperature in a short time.

II. THEORY

It has been shown³ that if a semi-infinite solid is subjected to a step-function heating pulse which is localized within a vanishingly thin disk of diameter d at the surface, then

$$(1) \quad T = \frac{E}{\pi^{3/2} JKd} \tan^{-1} \left[\left(\frac{4Kt}{\rho c d^2} \right)^{1/2} \right]$$

where T is the temperature rise above ambient at time t measured from the application of the heating pulse, and E is the power of the heating pulse, while the material constants K = thermal conductivity, ρ = density, and c = specific heat, and J is the calorie-joule conversion factor. In the derivation of this equation, heat loss by radiation has been neglected.

It is seen from eq. 1 that T monotonically increases with time until a saturation temperature T_{∞} is attained, where

$$(2) \quad T_{\infty} = \frac{E}{2\pi^{1/2} JKd} .$$

(Here E equals the product of the accelerating potential and the beam current).

Further, a characteristic time

$$(3) \quad \tau = \frac{\rho c d^2}{4K}$$

can be defined as the value of t corresponding to $T = T_{\infty}/2$. (Compare¹ Smith's characteristic time of $\rho c d^2/K$). Consider for example a 10 kv, 0.5 μ amp beam impinging upon a 1 μ diameter spot on a thick piece of soft glass. For that case⁴ $K = 4 \times 10^{-3}$ cal/sec cm^oC), $\rho = 2.20$ g/cm³, $c = 0.18$ cal/g^oC. Then $T_{\infty} = 845^{\circ}$ C and $\tau = 0.248$ μ sec. Such temperature rises and time constants would be eminently satisfactory for certain memory schemes.⁵

III. EXPERIMENT

To test the above theory a pulsed 20 kv electron beam was focussed upon a vapor-deposited thin-film thermocouple which fed an oscilloscope, so that the temperature vs time behavior could be monitored directly. The thermocouple consisted of narrow (100μ) strips of Cu ($4,000 \text{ \AA}$ thick) and Ni ($1,000 \text{ \AA}$ thick) film on a 1 mm soft-glass substrate; the Ni strip intersected (and overlay) the Cu strip at 90° . Such thermocouples were calibrated by reading the emf generated upon heating in an oil bath; a linear temperature vs emf curve was obtained with a slope of 48.5°C/mv (compare⁶ Bullis' value of 43.5°C/mv).

The electron beam was produced by a standard three-element electron gun employing a tungsten hair-pin filament. A specially-made magnetic electron-lens was mounted in the vacuum chamber a few cm from the thermocouple target; the beam was positioned on the thermocouple junction by a deflection-coil system after adjusting for focus with the aid of a nearby fluorescent screen. Because of the large spherical aberration and astigmatism of the lens it was necessary to delimit the beam by a physical aperture placed close to the thermocouple junction; the aperture was positioned with a light microscope and secured by double-faced teflon tape directly to the soft-glass substrate. Apertures 25, 50, 75 and 100μ in diameter were used.*

The dc beam current passing through an aperture was first measured by using the thermocouple as a Faraday cell. Then the beam was periodically

* For the case of the aperture diameter d less than the thermocouple strip width, a decrease in thermal emf is expected because of the shorting effect of the shielded portion of the thermocouple. The experiments indicate that this effect is not large (Table I).

pulsed in amplitude by sweeping it away from a special aperture placed before the lens. The resulting current pulses were square and several hundred millisec long, and caused corresponding temperature pulses which were displayed and photographed on an oscilloscope* (Fig. 1). An extended time scale (Fig. 1b) enabled more precise measurements of T vs t , while the contracted time scale (Fig. 1a) permitted measurement of T_{∞} .

The range of 20 kv electrons in Cu or Ni is⁷ 9,000 Å. Since the thermocouple junction was about 5,000 Å thick, nearly all the energy was absorbed in the thermocouple junction. Furthermore, since the ratio of glass-substrate thickness to thermocouple thickness was about 2,000, the approximation that the glass is "semi-infinite" is good.

The accuracy and reproducibility of this experiment was very poor. The major difficulties arose from drifts in the various power supplies, 60 cycle pickup in the unshielded column, and the poor electron optics. Although data were taken at accelerating potentials of both 10 and 20 kv, the 10 kv data were rejected because ac pickup caused unacceptably bad accuracy.

* Cooling curves are also displayed in Fig. 1. Although such curves follow the general trends predicted by theory, they were not quantitatively studied.

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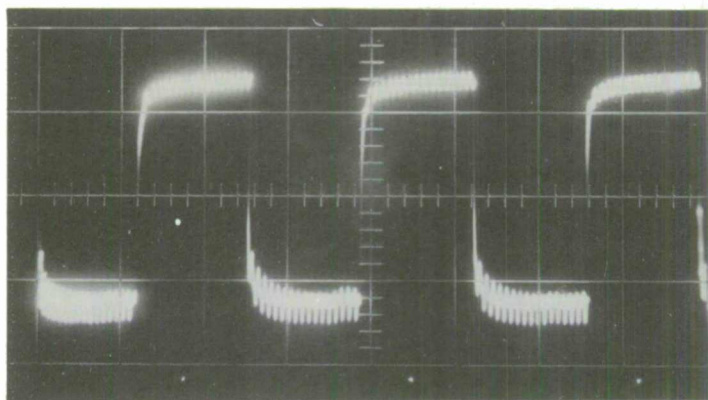


Fig. 1a. Oscilloscope trace of thermocouple emf vs time for 20 kv, 6.1 μ amp beam through a 75 μ aperture. Thermocouple calibration: 48.5 $^{\circ}$ C/mv. Temperature increases downward. Several complete heating and cooling cycles displayed. Vertical scale 2.5 mv/division; horizontal scale 200 millisec/division.

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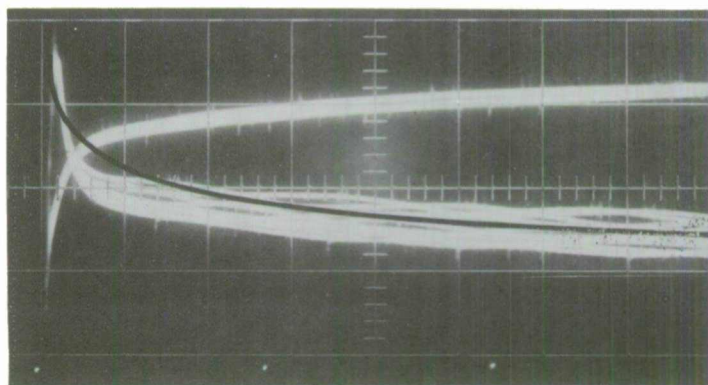


Fig. 1b. Superimposed heating and cooling cycles for same conditions as in Fig. 1a. Black line is theoretically predicted heating curve. Vertical scale 2.5 mv/division; horizontal scale 1 millisec/division.

IV. ANALYSIS

It is possible to rearrange eq. 1 to read

$$(4) \quad t / \left[\tan \left(\frac{\pi T}{2T_{\infty}} \right) \right]^2 = \tau .$$

All quantities on the left side of eq. 4 are experimentally measureable from the photographs (e.g. Fig. 1) so that, for a given aperture, estimates of τ can be calculated for various values of t . Values corresponding to very short and to very large values of t were ignored because it is felt that they were comparatively inaccurate.

The resulting values of τ are plotted against the square of the aperture diameter, d^2 , in Fig. 2. It is seen that the data are widely scattered; furthermore the reproducibility is poor as illustrated by the two sets of data (crosses and circles) taken for the 75μ aperture. Also, the data for $d = 100\mu$ seem to give far too low τ values; this result is not understood.* (On the other hand, at 10 kv reasonable values of τ ranging from 15 to 50 millisec were obtained). If the data for $d = 100\mu$ are ignored, a straight line can be drawn through the remaining data with a slope $\tau_0 = 14.4 \text{ sec/cm}^2$. From eq. 3 and the tabulated parameters,⁴ $t_0 = \rho c / 4K = 29.8 \text{ sec/cm}^2$. In view of the large experimental uncertainty, the agreement can be considered satisfactory.

Using the experimental value of τ_0 , T vs t was calculated for the 75μ aperture, and the results are plotted directly on Fig. 1b. It is seen that the calculated curve shows the same trend as the experimental curve, but rises in temperature somewhat more slowly.

*The thermocouple was apparently damaged by the beam since it created a small hole through the junction. Thus in this case the beam may have been inadvertently focussed to a spot of smaller diameter than the aperture.

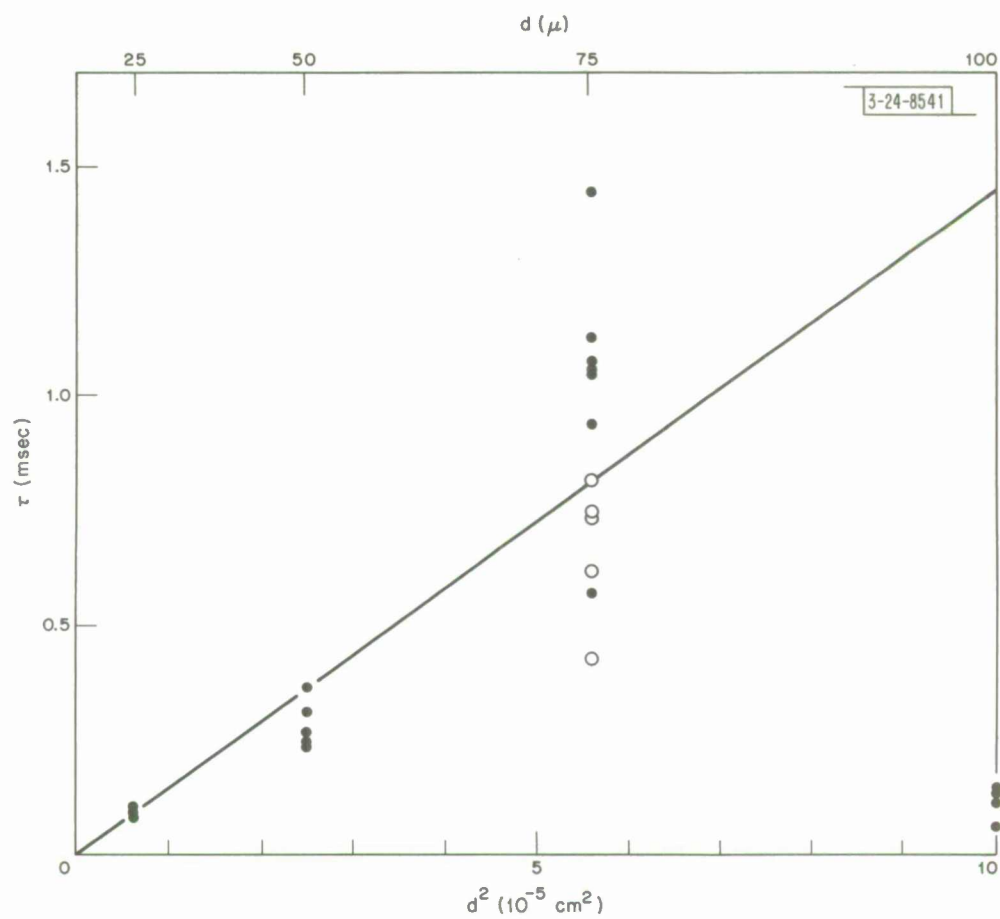


Fig. 2. Characteristic heating time τ vs square of aperture diameter, d^2 .

In Table I the values of T_{∞} calculated from eq. 2 are compared with those obtained experimentally. Again it is seen that fair agreement between theory and experiment is obtained, except for the anomolous case of the 100μ aperture.

V. DISCUSSION

With the crude apparatus available it has been possible to demonstrate only rough agreement with the thermal theory. Thus it can be said only that the heating (and cooling) curves of Fig. 1 follow the general trends of the theory, and that the data are apparently consistent with eq. 3. It is noted from Fig. 2 that the smallest achieved value of τ (for $d = 25\mu$) was about $100 \mu\text{sec}$; on the other hand, extrapolation of Fig. 2 predicts the satisfactory value of $\tau = 0.144 \mu\text{sec}$ for $d = 1\mu$.

It is clear that the present experiments could be greatly improved by the use of better electron optics to give a stable, pickup-free beam which could be delimited by focussing and not by apertures. In this way values of d down to 1μ could be attained. For such small values of d , a choice of some temperature-dependent phenomenon other than thermoelectric might be more appropriate.

VI. ACKNOWLEDGEMENTS

G. P. Weiss is thanked for designing some of the apparatus, and the skillful and patient work of C. W. Westcott in operating the equipment is gratefully acknowledged.

TABLE I

Aperture Diameter d	Beam Current i	T_{∞} (Computed)	T_{∞} (Experimental)
25 μ	1.2 μ amp	161 $^{\circ}$ C	133 $^{\circ}$ C
50	3.1	208	220
75	6.1	275	397
100	3.0	100	247

REFERENCES

1. D. O. Smith, IEEE Trans. Magnetics MAG-3, 433 (1967).
2. D. O. Smith, IEEE Trans. Magnetics MAG-3, 593 (1967).
3. L. G. Pittaway, Brit. J. Appl. Phys. 15, 967 (1964).
4. Y. S. Touloukian, "Thermophysical Properties of High Temperature Solid Materials" (Macmillan Co., New York, 1967), Vol. 4.
5. D. O. Smith, IEEE Trans. Magnetics MAG-4, (1968).
6. L. H. Bullis, J. Sci. Instrum. 40, 592 (1963).
7. M. v. Ardenne, "Tabellen zur angewandten Physik," (VEB Deutscher Verlag der Wissenschaften, Berlin, 1962), Vol. 1, p. 160.

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