that temperature spikes, contrary to the general speculation by Volmer,[2] do not serve in the present case as nuclei for melting. Although so far we have seen only melting patterns on InSb and failed to observe patterns on Ge specimens in a trial run, we feel that in the future it may conceivably be possible to observe similar patterns for Si and Ge under proper experimental conditions.

* Supported in part by the U. S. Air Force through the Office of Scientific Research of the Air Research and Development Command.
[1] G. K. Teal and J. B. Little, Phys. Rev. **78**, 647 (1950).
† X-ray investigation by George Baker is gratefully acknowledged.
[2] M. Volmer, *Kinetik der Phasenbildung* (T. Steinkopff, Danzig, 1939).

Resistance Thermometer for Transient High-Temperature Studies*

J. Rabinowicz, M. E. Jessey, and C. A. Bartsch
Guggenheim Aeronautical Laboratory, California Institute of Technology, Pasadena, California
(Received September 6, 1955)

CURRENT interest in ultra-high-speed flight has stimulated the development of the shock tube as a device for simulating high stagnation temperatures in supersonic flow. The main difficulty in these tests is the extremely short duration of uniform flow, of the order of 100–500 μsec. This time interval dictates extremely fast response of any measuring instrument applied to shock tube research.

Recently Emrich and Chabai,[1] W. Bleakney, A. Hertzberg, A. Kantrowitz, and others have utilized metallic films as resistance thermometers to measure transient surface temperatures and heat transfer rates. In this note we describe a gauge developed at GALCIT utilizing a thin platinum film which has a response time of less than 1 μsec, linear output of about 1.5–2.5 mv/°C, durability, repeatability, and very small resistance change over a large number of test runs.

The gauge shape and size can be made to fit any model required. The sensitive element is a very thin platinum film sputtered over an insulator backing plate (usually Pyrex glass) to a thickness of the order of 10^{-6} cm. The sputtering technique has to be developed by some trial and error procedure to determine the exact conditions. For a description of such procedures the reader is referred to references 2 and 3. The thickness of the film is controlled by sputtering time, which was varied between 15 minutes and $1\frac{1}{2}$ hours. The film was later baked in an oven at 1100°F for $\frac{1}{2}$ hour and air-cooled.

The leads were attached by sputtering the ends of the element and baking it. After sputtering the top sensitive film and baking it, wire leads were soft-soldered to the ends. Typical stages of gauge assemblies are shown in Fig. 1. A sensitive element was placed along the "stagnation line" of a circular cylinder and was backed by blotting paper to reduce the chance of breakage of the glass. Similarly a gauge was fitted for wall temperature studies. Both are shown in Fig. 2.

The film is operated at constant current by connecting it in series with a larger resistance. The initial resistance of the film is measured with a bridge and the initial current is also measured, both to an accuracy of $\frac{1}{2}$%. Calibration runs show that the relation between resistance and temperature is very nearly linear. In that case the gauge output is

$$T_f - T_0 = \frac{\Delta E}{I_0 R_0 \alpha},$$

where α is the coefficient of resistivity. In the shock tube a film temperature rise of about 50 to 100°C can be expected. For a typical gauge ($R_0 = 50$ ohms, $I_0 = 10 \times 10^{-3}$ amp, $\alpha = 0.003$ 1/°C), an output of about 100 millivolts is recorded.

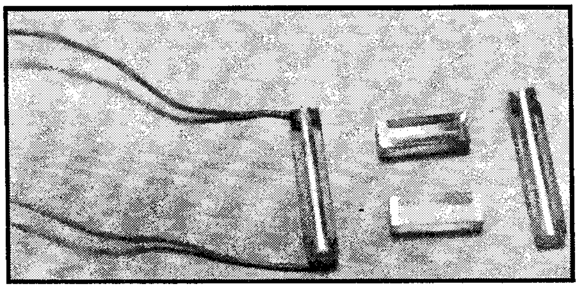

FIG. 1. Transient temperature gauges.

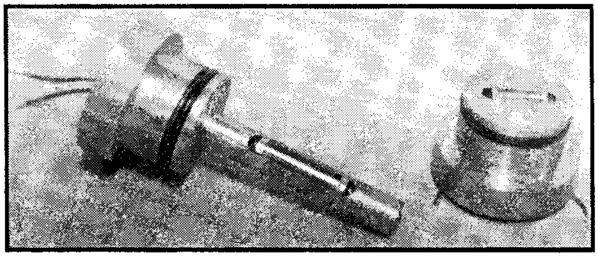

FIG. 2. Models for heat transfer studies in shock tube.

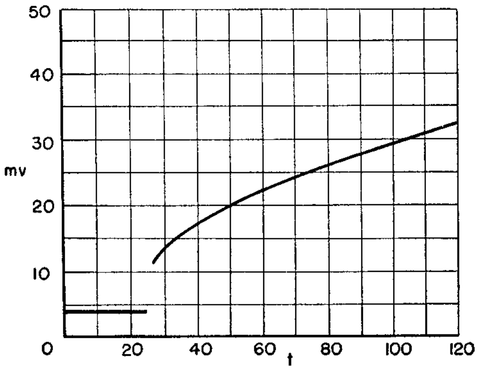

FIG. 3. Gauge response at stagnation point of a cylinder in the shock tube—sweep 10 μsec/div., $M_s = 7$, $P_1 = 3$ mm Hg.

Experimental evidence shows a response time of better than 1 μsec, and there is no doubt that the response time is more than adequate for most heat transfer studies in the shock tube.

In the preliminary heat transfer tests the heat transfer rates at the stagnation point of a cylinder and on the shock-tube wall were recorded. The heat transfer at the stagnation point on a blunt body is proportional to the difference between the stagnation enthalpy h_s and the enthalpy corresponding to wall temperature h_w. At very high gas temperatures $h_s \gg h_w$, and so the heat transfer rate is very nearly constant for the duration of experiment. Now, the classical solution for surface temperature *vs* time for a semi-

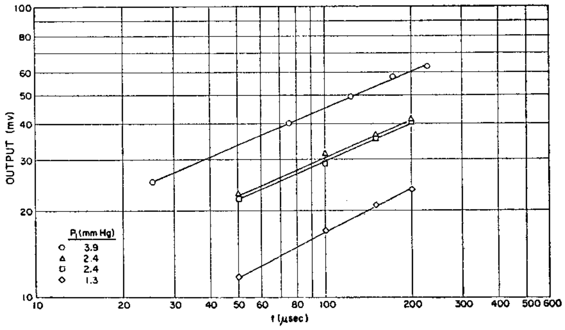

FIG. 4. Response of transient temperature gauge at a stagnation point in the shock tube, $M_s = 7.0$.

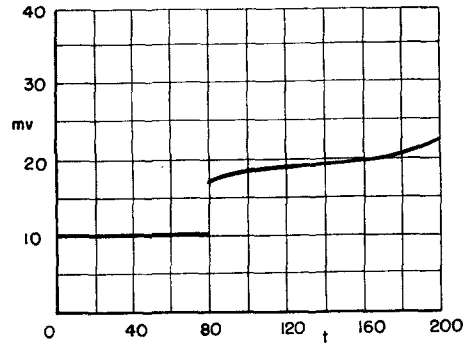

FIG. 5. Gauge response on shock-tube wall-sweep 20 μsec/div., $M_s=7$, $P_1=5$ mm Hg.

infinite body with constant rate of heat input at the surface is as follows (reference 4):

$$T(0,t)=\frac{2}{\sqrt{\pi}}\cdot q\cdot\left(\frac{t}{C_p\rho k}\right)^{\frac{1}{2}}.$$

A reproduction of an oscilloscope record verifying this parabolic temperature-time relation is shown in Fig. 3. The results of several runs are plotted in Fig. 4.

On the wall of the shock tube the laminar boundary layer grows like $1/\sqrt{t}$ behind the shock wave, and the heat rate decreases like $1/\sqrt{t}$. For this heat input the solution is $T(0,t)=$ constant,† i.e., a step function in surface temperature, as shown by the oscilloscope trace in Fig. 5.

Quantitative information on heat transfer rates is now being obtained in the shock tube at GALCIT. These preliminary results indicate that this gauge can be very useful in measuring heat transfer rates and surface temperatures in many applications where fast response is required, such as in a ballistic range, flight test of missiles, rocket engines, etc.

* This work is part of a broad program of experimental and theoretical research on hypersonic and related flow problems sponsored jointly by the U. S. Army Ordnance and Air Force under Contract No. DA-04-495-Ord-19.

[1] A. J. Chabai and R. J. Emrich, J. Appl. Phys. 26, 779 (1955).
[2] J. Strong, *Procedures in Experimental Physics* (Prentice-Hall, Inc., New York, 1946).
[3] C. H. Bachman, *Techniques in Experimental Electronics* (John Wiley and Sons, Inc., New York, 1948).
[4] H. S. Carslaw and J. C. Jaeger, *Conduction of Heat in Solids* (Clarendon Press, Oxford, England, 1947).
† R. Bromberg, private communication.

Note on Positive Ion Transit Time in Glow Discharge Tubes

CHAI YEH
Department of Electrical Engineering, University of Kansas, Lawrence, Kansas*
(Received September 19, 1955)

WE have observed an approximate correlation between the transit times of ions in the glow discharge cathode fall and the frequency at which the impedance of the discharge changes from inductive to capacitive. The physical process is presumed to be the following: If a small ac voltage is superimposed on the dc discharge, ions produced at the edge of the negative glow will not arrive at the cathode in phase, and if the frequency is correct, will arrive exactly out of phase. It is this frequency that determines the transition.

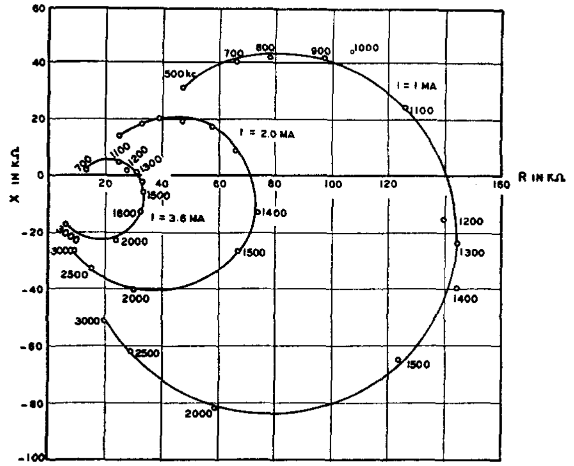

FIG. 1. Typical impedance curves of a glow discharge tube. Reactance X is plotted against resistance R in kilo-ohms at different frequencies for a discharge current $I=1.0$, 2.0, and 3.6 milliamperes, respectively.

In calculating the ion transit time, we assume that the ions are produced at the edge of the glow and that their velocity is a function of E/p, and therefore of position. The drift velocity as given by Hornbeck[1] is proportional to E/p at low fields and to $(E/p)^{\frac{1}{2}}$ at high fields. The field is presumed to drop from a high value at the cathode to zero at the edge of the negative glow according to the "mobility" solution given by Warren.[2] Thus the transit time

$$\tau=\int_0^{d_c}\frac{dx}{v(x)}$$

diverges. We have overcome this difficulty by assuming that the ions are produced a distance δ toward the cathode from the edge of the glow. Thus,

$$\tau=\frac{3}{2}\frac{dc^{\frac{3}{2}}}{k_2}\left(\frac{p}{2V_s}\right)^{\frac{1}{2}}\left\{\frac{\pi}{2}-\sin^{-1}(1-y_1^{\frac{2}{3}})^{\frac{1}{2}}-y_1^{\frac{1}{3}}(1-y_1^{\frac{2}{3}})^{\frac{1}{2}}\right\}$$
$$+\frac{3}{2}\frac{dc^2}{k_1V_s}\{y_1^{\frac{1}{2}}-y_2^{\frac{1}{2}}+\ln|(1+y_2^{\frac{1}{2}})(1-y_1^{\frac{1}{2}})^{\frac{1}{2}}|$$
$$-\ln|(1+y_1^{\frac{1}{2}})(1-y_2^{\frac{1}{2}})^{\frac{1}{2}}|\}. \quad (1)$$

Where

$$y_1=d_1/d_c \quad\text{and}\quad y_2=(d_c-\delta)/d_c.$$

Here, d_c is the cathode fall distance, p is the pressure, and V_s is the sustaining voltage. k_1 is a coefficient relating the drift velocity of the ions to the applied field in the low field region (see reference

TABLE I. Data and results of computation of the transit time by Eq. (1).

Tube	Gas kind	Filling pressure in mm Hg	Sustain potential V_s in volts	k_1[a] $\frac{cm^2}{volt}\frac{mm\ Hg}{sec}$	k_2[a] $\frac{cm^{\frac{3}{2}}}{sec}\left(\frac{mm\ Hg}{volt}\right)^{\frac{1}{2}}$	δ cm	τ'[b] Observed transit time sec	τ Calculated transit time by Eq. (1).	τ'/τ
1	Ne	30	109	2.9×10^3	1.6×10^4	16×10^{-5}	2.2×10^{-7}	2.02×10^{-7}	1.09
2	A	31	100	1.0×10^3	0.82×10^4	8×10^{-5}	0.67×10^{-7}	1.26×10^{-7}	0.53
3	Ne	60	107	2.9×10^3	1.6×10^4	8×10^{-5}	1.25×10^{-7}	1.07×10^{-7}	1.17
4	He	50	115	7.5×10^3	4.0×10^4	14×10^{-5}	1.52×10^{-7}	1.75×10^{-7}	0.87
5	Ne	10	114	2.9×10^3	1.6×10^4	50×10^{-5}	4.35×10^{-7}	5.97×10^{-7}	0.73

[a] k_1 and k_2 are taken from Hornbeck's data in reference 1.
[b] τ' is computed from the cross-over frequency f_c in the experiment such that $\tau'=1/2f_c$.