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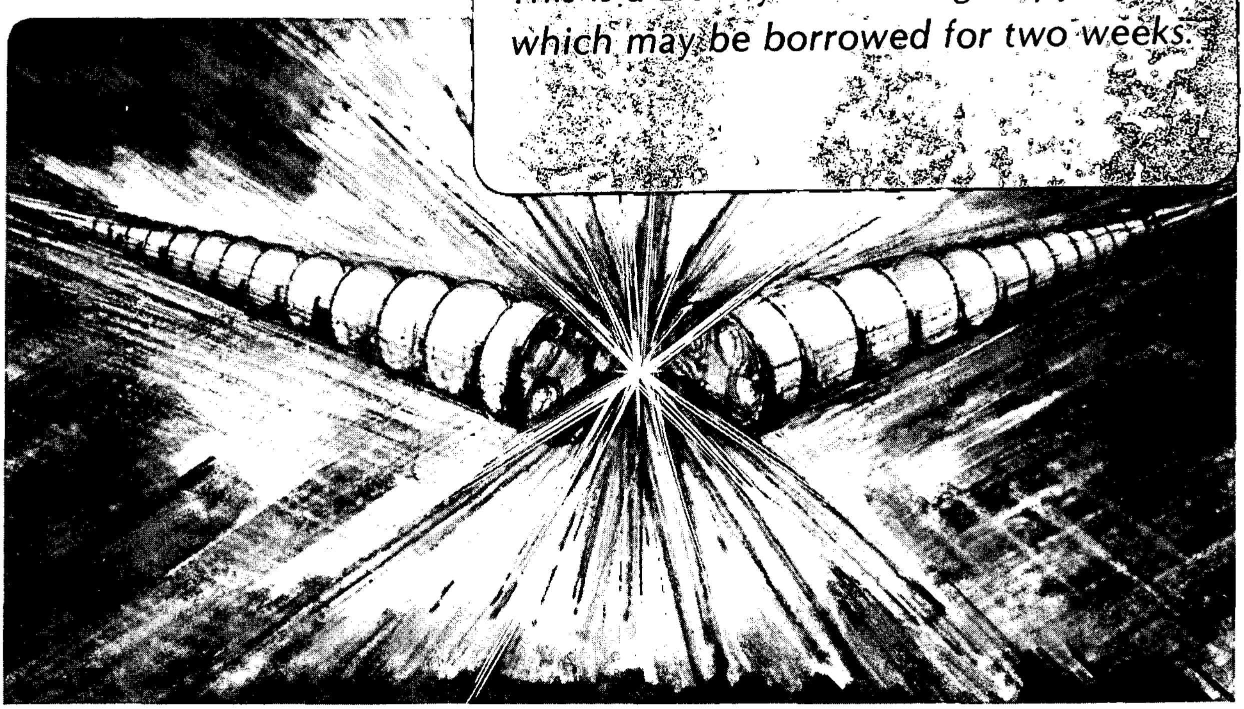

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LANTHANUM HEXABORIDE (LaB_6) RESISTIVITY MEASUREMENT*

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ABSTRACT

In the development of high power free electron lasers, intense electron beams are required. Large area, directly-heated lanthanum hexaboride cathodes have been proposed as the electron emitter. To aid in the design of the cathode, the resistivity of lanthanum hexaboride as a function of material density and temperature has been measured.

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It has been known for some time that lanthanum hexaboride (LaB_6) is a good material for use as an electron emitter.[1,2,3] It has also been demonstrated that <u>directly-heated</u> LaB_6 cathodes, either in the form of filaments or in a coaxial geometry can be operated successfully in a plasma source.[4,5,6] In some applications, such as high power free electron lasers, large area cathodes are required. A directly-heated LaB_6 electron emitter has been proposed for the generation of intense electron beams.[7] By balancing the ohmic heating with the cooling power, the proper shape of the cathode can be computed. The resistivity of LaB_6 is an important parameter in the computation. However, there is little available data on the resistivity of LaB_6 as a function of temperature and material density. To aid in the design of the proposed cathode, measurements of the resistivity of various densities of LaB_6 at different temperatures have been performed. This paper describes the apparatus, test procedures and the results of these measurements.

The manufacture of solid lanthanum hexaboride is normally accomplished by sintering of LaB_6 powder under various temperatures and pressures to obtain the desired material density.[1,8] In principle, the maximum obtainable density is 4.7 g/cm^3. Densities ranging from 60% to 95% of this value are readily available. Higher densities can be produced, but at a higher manufacturing cost. LaB_6 material with densities lower than 60% is quite soft and structurally weak, and therefore is not suitable for cathode use. For high densities, LaB_6 has ceramic-like properties in hardness and requires special tooling and techniques for machining. Most data available in the literature correspond to densities of 80 to 85%, which is the most common off-the-shelf material available.[1,2,3,9]

The experimental set-up is shown in Figure 1. The test apparatus was installed in a vacuum chamber equipped with a window which provided a full view of the LaB_6 sample. An optical pyrometer (wavelength 0.65 microns) was used to measure sample temperature. The window transmission was separately checked with a reference light, and a transmission loss of approximately 2% was determined. An emissivity of 0.7 was used for correction of the observed temperature.[9]

The LaB_6 samples[10] were cylindrical rods of approximately 0.63 cm diameter and 5 cm length. Material density of the tested samples varied from 60% to 95%. The test fixture was designed to hold the rods in compression between the current supplying contacts. The difference in voltage between two points on the LaB_6 rod was measured with two voltage sensing contacts (typically 2.3 cm apart). The central, most uniform temperature section of the LaB_6 rod was chosen for the voltage measurements; temperature variations along the section were in the range of 2%. To avoid reactions with the LaB_6, rhenium was used for all contact surfaces.

Each LaB_6 sample was in turn installed in the assembly. Current and voltage readings were first recorded at a very low current to establish the resistivity, ρ, at ambient temperature. Results of these measurements are represented by the five data points shown in the lower part of the curves in Fig. 2.

The applied heater current was then increased gradually until the LaB_6 temperature came within the pyrometer's range (~ $800^{0}C$). Voltage, current and temperature readings were recorded after allowing the sample to come to equilibrium. All LaB_6 samples were tested several times at various temperatures to assure repeatability. It was found that all test runs were in close agreement.

Figure 2 is a plot of the measured resistivity, ρ, for six different LaB_6 densities as a function of temperature. It can be seen that ρ increases approximately linearly with temperature. For a given temperature, ρ decreases as the material density increases. Note that there is nearly a factor of four difference in resistivity between the 60% and the 95% material.

For directly heated cathodes, the cathode resistance drops as size is scaled up. Thus to keep cathode impedances matched to conveniently available power supplies, it is advantageous to use the lower density materials for larger cathodes.

Looking at Fig. 2, it can be observed that straight lines through the data points approximately intersect at the origin. Thus an empirical relationship between the resistivity, the density, and the temperature can be written in the form:

$$\rho = \rho' \cdot T = A \cdot D^n \cdot T \qquad (1)$$

where A and n are constants, D is the material density fraction (defined as the ratio of the measured density over the theoretical density), and ρ' is the resistivity coefficient. The resisitivity coefficient ρ' for each density is just the slope of the corresponding curve.

Figure 3 shows a logarithmic plot of ρ' versus D. Because the data points lie roughly on a straight line, the D^n power law is a good approximation. Since $\ln \rho' = \ln A + n \ln D$, the constants n and A can be obtained from the slope, and from the value of the curve at $D = 1$, respectively. Hence $n = -8/3$, and $A = 4.1 \times 10^{-8}\ \Omega\ cm\ K^{-1}$. Thus, a good approximation for the resistivity of LaB_6 for different material densities at various temperatures can be written as:

$$\rho(\Omega\ cm) = 4.1 \times 10^{-8}(\Omega\ cm\ K^{-1}) \cdot D^{-8/3} \cdot T(K) \qquad (2)$$

Experiments are now planned to determine other LaB_6 parameters such as coefficient of thermal expansion and emission density as a function of material density and temperature.

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References

1. J. M. Lafferty, J. Appl. Phys. 22, 299 (1951).
2. H. Ahmed and A. N. Broers, J. Appl. Phys. 43, 2185 (1972).
3. W. H. Kohl, Handbook of Materials and Techniques for Vacuum Devices, (Reinhold, New York, 1967).
4. K. N. Leung, P. A. Pincosy, and K. W. Ehlers, Rev. Sci. Instrum. 55, 1064 (1984).
5. P. A. Pincosy, K. N. Leung, Rev. Sci. Instrum. 56, 655 (1985).
6. K. N. Leung, D. Moussa, and S. B. Wilde, Rev. Sci. Instrum. 57, 1274 (1986).
7. K. Gordon, D. Kippenhan, K. N. Leung, D. Moore, D. Moussa, S. B. Wilde and M. D. Williams, Bull. Am. Phys. Soc. 31, 1507 (1986).
8. J. M. Lafferty, Phys. Rev. 79, 1012 (1950).
9. G. V. Samsonov, High-Temperature Compounds of Rare Earth Metals with Nonmetals (Consultants Bureau, New York, 1965).
10. LaB_6 material obtained from Cerac, Inc. Milwaukee, WI 53201.

Figure Caption

Fig. 1 Apparatus for measuring the resistivity of LaB_6 samples.

Fig. 2. Resistivity of LaB_6 as a function of temperature, for material density fractions ranging from .60 to .95.

Fig. 3 Resistivity coefficient of LaB_6 as a function of density fraction.

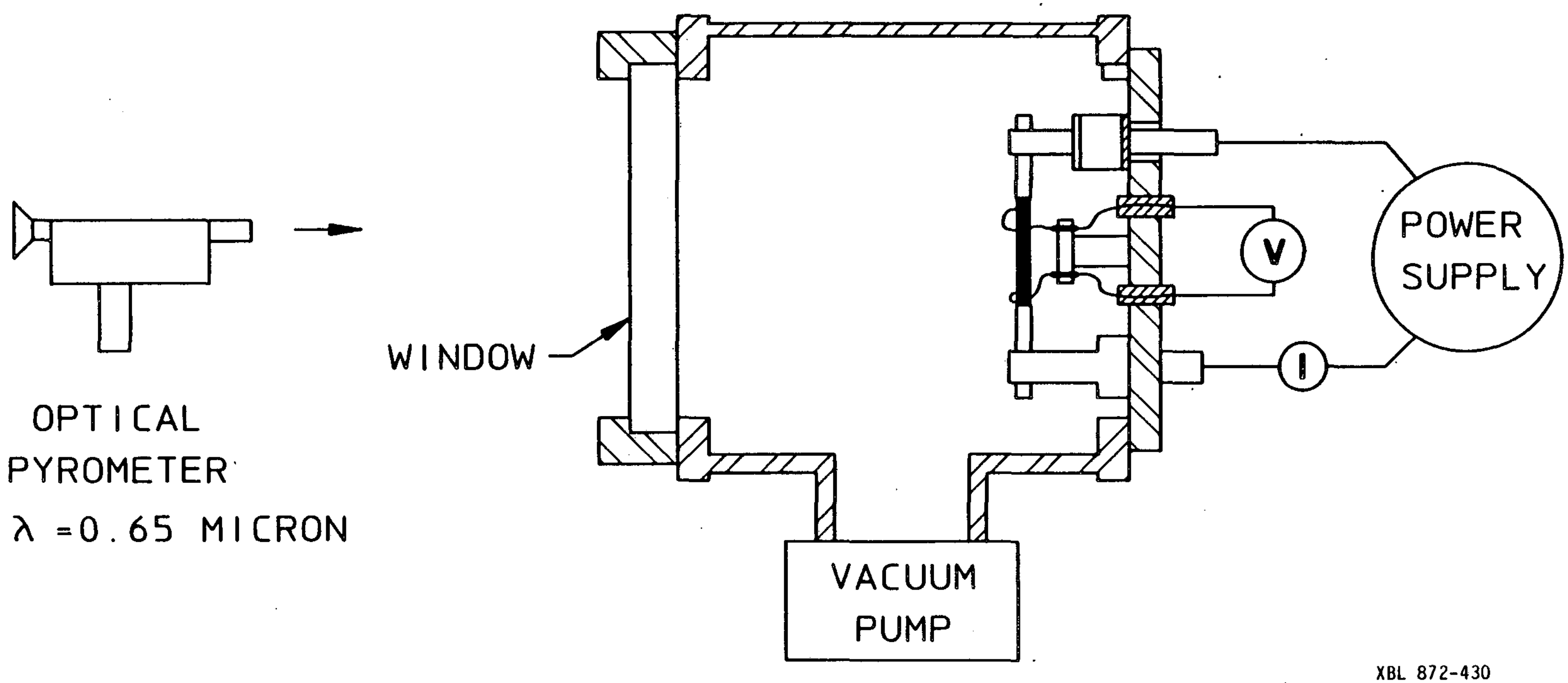
OPTICAL
PYROMETER
λ =0.65 MICRON
WINDOW
VACUUM
PUMP
V
I
POWER
SUPPLY
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Fig. 1

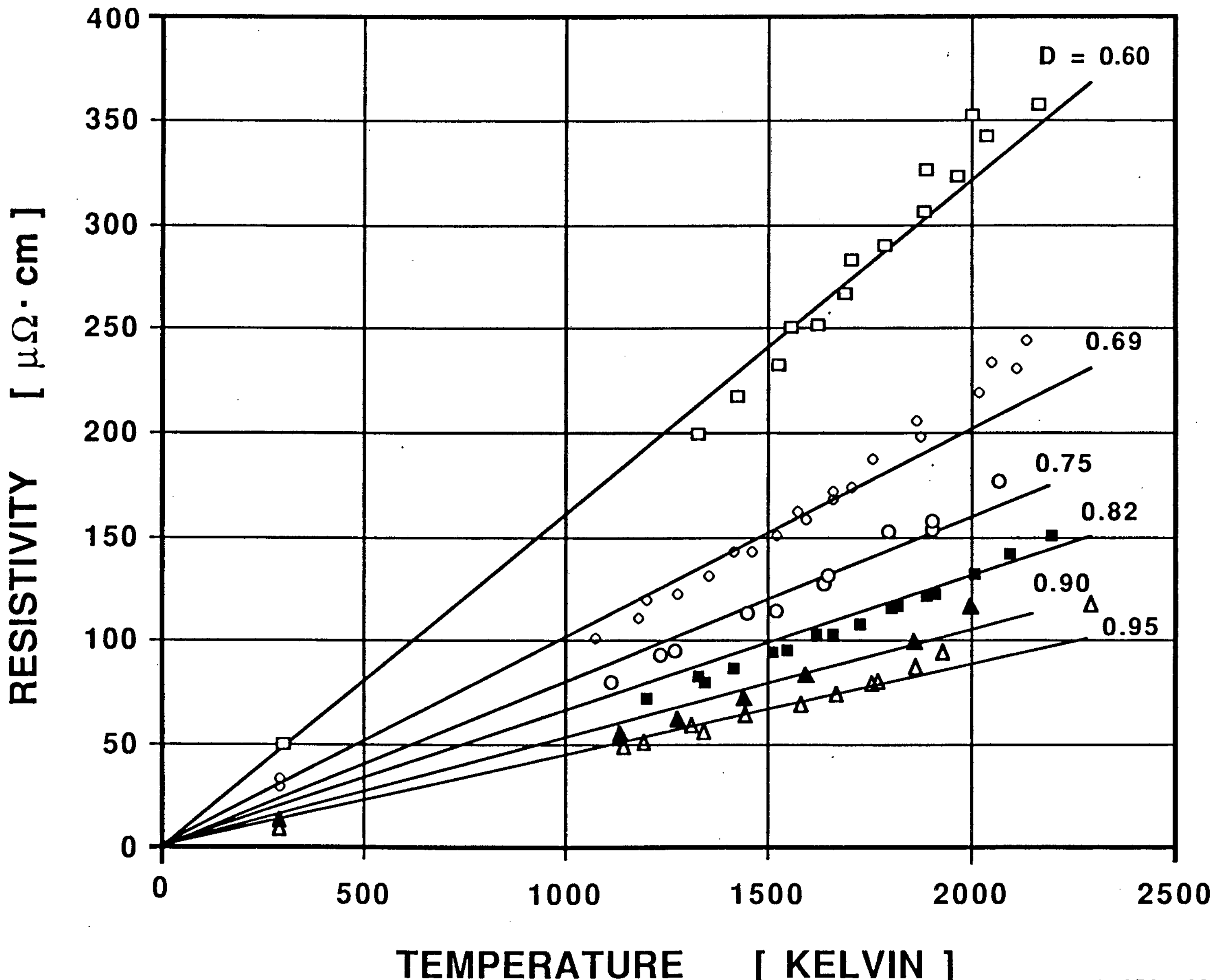

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Fig. 2

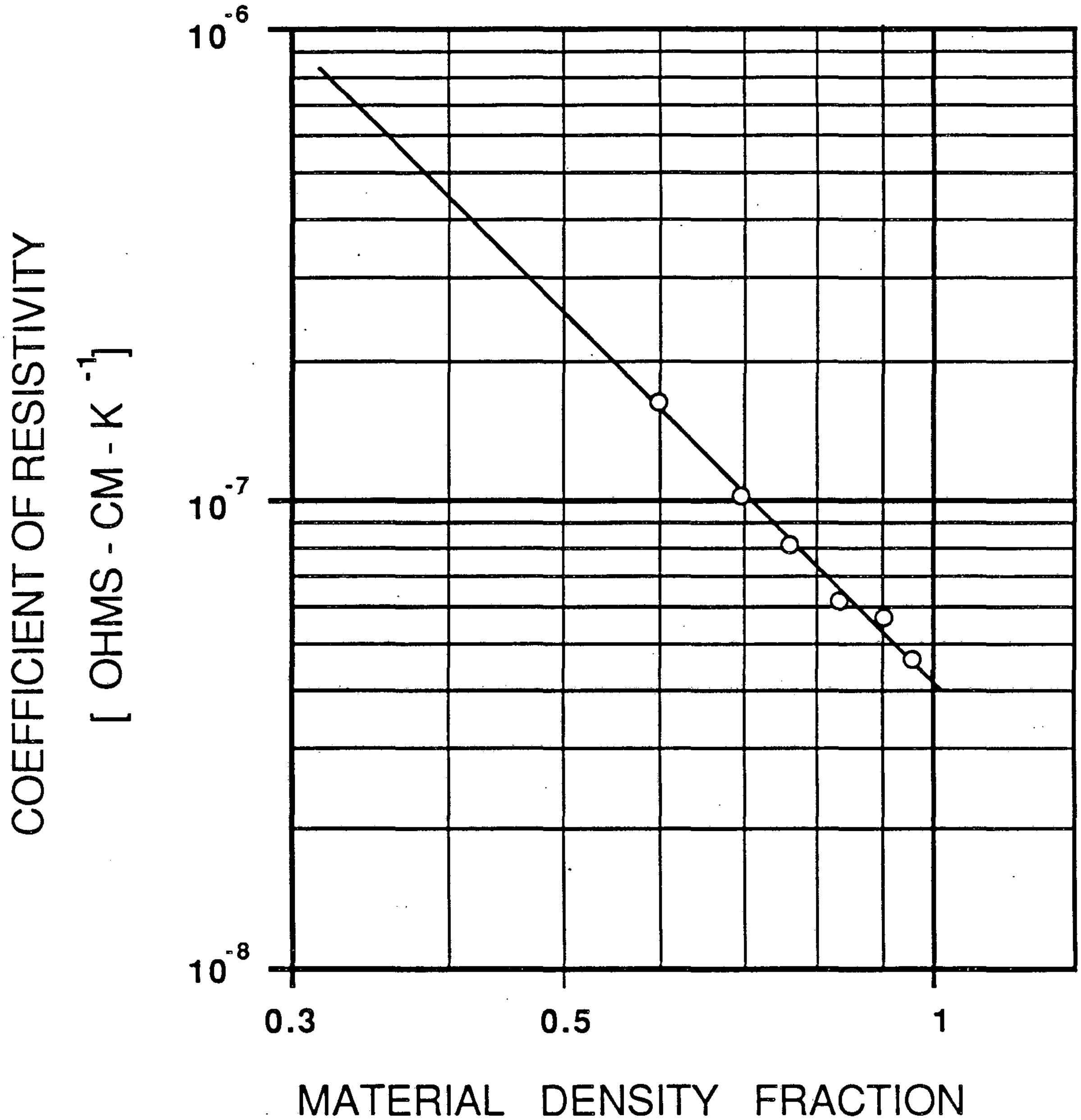

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Fig. 3

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