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Anisotropy of thermionic electron emission values for LaB₆ single-crystal emitter cathodes

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Measurement of thermionic electron emission values for pointed LaB₆ single-crystal emitter cathodes has shown that $\langle 110 \rangle$ axial orientations yield emission values ten times higher than $\langle 100 \rangle$ orientations at 1545°K. Minimum values were obtained for the $\langle 510 \rangle$ directions. These findings seem encouraging in achieving perhaps two orders of magnitude higher emission fluxes as compared to tungsten emitters.

PACS numbers: 79.40.+z, 84.60.Ny, 07.80.+x

The potential use of LaB₆ as an electron emitter has received considerable attention since the investigations of Lafferty¹ on boride cathodes. Early work by Broers² and Vogel³ clearly demonstrated the superiority of LaB₆ as an electron emitter over conventional tungsten hairpin filaments for application in a scanning electron microscope. Practical application of high-intensity emitter cathodes for electron microscopes and electron-beam exposure systems, however, requires detailed information on emission characteristics, the angular variation of electron emissivity, and stability. Further detailed data is required on temperature effects, vacuum requirements, tip shaping, and the compatibility of structural mounting materials with LaB₆. Finally, much work remains to be done on crystalline imperfections and strains and their relation to ultimate emitter performance.

Recent work by Swanson *et al.*,⁴ on the work function values from (100) single-crystal LaB₆ has indicated the possibility of yet lower values of Φ for other crystal directions.

We report results of a detailed study on measurements of electron emission anisotropy values for pointed single-crystal LaB₆ thermionic emitters designed for direct replacement of tungsten hairpin cathodes in a scanning electron microscope system. Actual details of the emitter mounting structure will be reported elsewhere.⁵

The test apparatus was mounted in an ion-pumped hard-seal testing chamber. Typical vacuum conditions during cathode testing were $\sim 5 \times 10^{-7}$ Torr after initial gas desorption. The test apparatus consisted of a Faraday-cup electron collector and picoammeter detector, a tantalum accelerating anode plate with a 1.0-mm-aperture hole, and an emitter mounting structure that contained a resistively heated single crystal of LaB₆. The crystal mounting structure was designed so as to be rotatable plus or minus 50° in one plane, with the axis of rotation made to be directly through the crystal tip. Deflector plates mounted between the anode and Faraday cup were included to aid in beam alignment.

Direct observation of emission patterns was achieved by constructing an accelerating plate coated with a thin layer of phosphor. Photoluminescence of the phosphor provided a direct visual record of emission

intensities in addition to the electrical measurements from the Faraday cup. A continuous display of emission patterns was achieved by angular rotation of the emitter mounting.

Single crystals were prepared by aluminum flux growth procedures⁶ from ultrahigh-purity elements. Details of crystal growth have been described elsewhere. Naturally faceted (100) single-crystal prisms were obtained from the crystal-growth runs having typical dimensions of 0.1 mm \times 0.1 mm \times 5–7 mm. Use of naturally faceted crystals enabled us to avoid mechanical shaping with the possible introduction of crystal defects that might be detrimental to electron emission characteristics.

Only the crystal tip was additionally shaped. Pointing was done electrolytically using an electrolyte of 20% HCl and 80% water. The cathode used was a tantalum strip and the bath held at room temperature. A dc potential of 10 V was applied to the cell. Tips were shaped very quickly (15 sec) and had a typical included

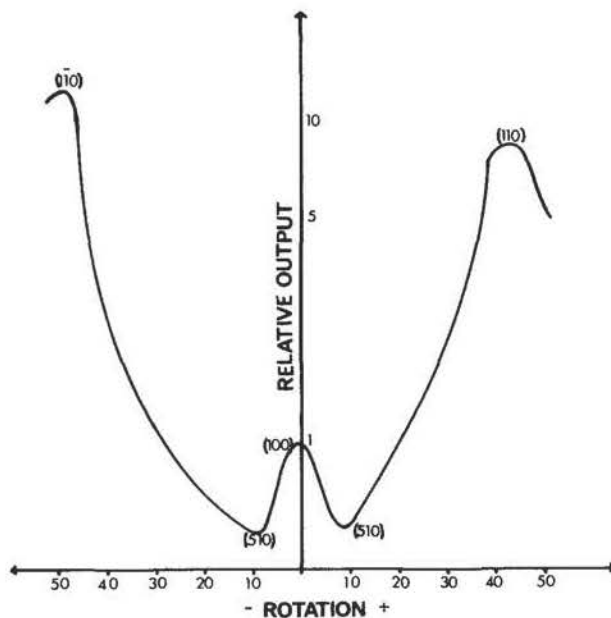


FIG. 1. Output current is plotted versus the rotation angle for a $\langle 100 \rangle$ axial orientation single crystal of LaB₆ at 1545°K. Maximum emission is seen for the $\langle 110 \rangle$ crystal direction.

angle of 30–45° with a 1–2-μm tip radius. Use of the electrolyte described by Shimizu⁷ produced tips with much smaller included angles.

The total output current from the Faraday cup is plotted versus the rotation angle in Fig. 1. This data was obtained with a <100> axial orientation single crystal. Emission values for the <510> crystal directions were one-half the values obtained for <100> directions, while <110> directions were ten times higher than <100> directions. Data shown was taken with an emitter tip temperature of 1545°K. Temperatures were measured with a calibrated pyrometer. Maximum values of electron emission were obtained for the <110> orientations at temperatures of somewhat in excess of 1600°K. Cathode current densities as measured for the <100> and <110> crystal directions at 1545°K were 5 and 50 A/cm², respectively. The <100> value agrees quite well with Seanson's⁴ data of 0.16 A/cm² at 1500°K and 33 A/cm² at 2000°K. The magnitude of the electric field at the emitter surface is estimated to be ~10⁹ V/cm. Field emission enhancement seems unlikely for our data since ~10⁻⁹ Torr and 10⁷ V/cm are normally required for significant field emission effects.

Visual emission patterns confirmed the above find-

ings. For <100> axial orientations, four bright spots were observed on the fluorescent screen forming a square pattern. For <110> orientations, a rectangular spot pattern was seen. Emission patterns for finely polycrystalline hot-pressed emitters, by contrast, produced a random array of spots on the screen. This pattern was unstable and continuously changed, probably resulting from emission from different crystallites at different times.

The above findings seem encouraging in achieving perhaps two orders of magnitude higher emission fluxes as compared to tungsten emitters. Application of these findings should prove useful for future work.

¹J. M. Lafferty, *J. Appl. Phys.* **22**, 299 (1951).

²A. N. Broers, *J. Phys. E* **2**, 273 (1969).

³S. F. Vogel, *Rev. Sci. Instrum.* **41**, 585 (1970).

⁴L. W. Swanson and T. Dickinson, *Appl. Phys. Lett.* **28**, 578 (1976).

⁵D. C. Joy, H. J. Leamy, S. D. Ferris, P. H. Schmidt, L. D. Longinotti, and Z. Fisk (unpublished).

⁶Z. Fisk, P. H. Schmidt, and L. D. Longinotti, *Mater. Res. Bull.* (to be published).

⁷R. Shimizu, Y. Kataoka, S. Kawai, and T. Tanaka, *Jpn. J. Appl. Phys.* **14**, 1089 (1975).

Magnetic fields due to impurity grains in laser-produced plasma

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Results of a numerical simulation model are given for the magnetic field produced by an impurity grain embedded in a dense inhomogeneous plasma.

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Megagauss magnetic fields have been measured in plasmas produced by focusing a laser pulse on to a solid target.¹ Similar thermoelectric field sources are associated with an impurity grain embedded in a dense plasma.² Thus if a laser pulse is focused on to a grainy target (e.g., Al dust in epoxy), the resulting plasma is expected to fill out with magnetic turbulence. This technique for seeding turbulence may have applications in the design of fusion targets.^{2,3} In this letter we give computer results for the field of a single impurity grain. The code on which our results are based is a derivative of the NRL laser-target code.^{4,5} Similar codes have been developed in other laboratories.⁶⁻⁹

A single axisymmetric impurity grain is considered to be located in a temperature gradient produced by holding the plasma temperature constant on two boundaries at $z = \pm \frac{1}{2}L$ as shown in Fig. 1. Hydrodynamics

is "frozen" and we self-consistently solve the complete magnetic field and thermal energy flow equations.¹⁰

$$\begin{aligned} \frac{\partial \mathbf{B}}{\partial t} = & -\frac{c^2}{4\pi} \nabla \times [\mathbf{r} \cdot (\nabla \times \mathbf{B})] - \frac{c}{eN_e} \nabla N_e \times \nabla T - \frac{c}{e} \nabla \times \left(\frac{\mathbf{R}_T}{N_e} \right) \\ & - \frac{c}{4\pi e} \nabla \times \left(\frac{1}{N_e} (\nabla \times \mathbf{B}) \times \mathbf{B} \right) + \frac{1}{e} \nabla \times \left(\frac{1}{N_e} \mathbf{J}_b \times \mathbf{B} \right) \\ & + c \nabla \times (\mathbf{r} \cdot \mathbf{J}_b), \end{aligned} \quad (1)$$

$$\frac{\partial E}{\partial t} = -P_{Br} + \nabla \cdot (\mathbf{K}_e \cdot \nabla T) + \frac{j_n^2}{\sigma_n} + \frac{j_1^2}{\sigma_1} + \frac{1}{eN_e} \mathbf{j} \cdot \mathbf{R}_T, \quad (2)$$

where

$$\mathbf{r} = \mathbf{b}\mathbf{b}\sigma_n^{-1} + (\mathbf{I} - \mathbf{b}\mathbf{b})\sigma_1^{-1} \quad (3)$$

is the resistivity tensor, E the thermal energy density,

$$\mathbf{j} = c/4\pi \nabla \times \mathbf{B} - \mathbf{J}_b \quad (4)$$