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Author(s)	Abe, Nobuyuki; Kato, Yutaka; Tomie, Michio
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# Development of an LaB<sub>6</sub> Cathode for High Power Electron Beam Welding<sup>†</sup>

Nobuyuki ABE\*, Yutaka KATO\*\* and Michio TOMIE\*\*\*

**KEY WORDS:** (LaB<sub>6</sub> Cathode)(Electron Beam Welding)(High Power)(Long-Term Stability)

The requirements of the cathode for thermal electron emission used for an electron gun in the field of thermal processing, especially for electron beam welding, are the ability to generate high power and a high energy density beam for long times with stability and flexibility of control. A tungsten cathode which is usually used needs a very high temperature for thermal electron emission. Decreasing this temperature suppresses the thermal distortion of the cathode and its supporter and stabilizes the fluctuation of the output beam. From this view point, the authors selected LaB<sub>6</sub> for cathode material because it has low work function and the ability to emit electrons at very low temperatures, and developed a directly heated type sintered LaB<sub>6</sub> cathode for high current electron beam generation. Furthermore, the characteristics of beam generation were investigated for this cathode.

**Figure 1 (a)** and (b) show the directly heated LaB<sub>6</sub> cathode which is mounted on an electron gun and its electric circuit. Carbon heaters set on both sides of the LaB<sub>6</sub> cathode increase the temperature of the cathode by thermal conduction through electric heating of the heater. Although any diameter can be used because the Joule heating method is involved, the cathode diameter for this experiment was selected by considering the required beam current and beam diameter for beam focusing with a magnetic lens. Under these conditions, cathode diameter of 4.0 mm and 5.0 mm were selected.

Cathode temperature  $T_C$  and cathode heating power  $W_C$  are plotted in **Fig. 2** for cathode diameters  $d_C$  of 4.0, 4.5 and 5.0 mm. At the upper limit temperature of 2015 K of the cathode, a heating power  $W_C$  of 92 W for 5.0 mm cathode was required. A tungsten cathode which emits the same thermal electron emission density requires a temperature of 3000 K and a heating power of

400 W. It can be seen that the heat consumption of a LaB<sub>6</sub> cathode is much more lower than that of a tungsten cathode.

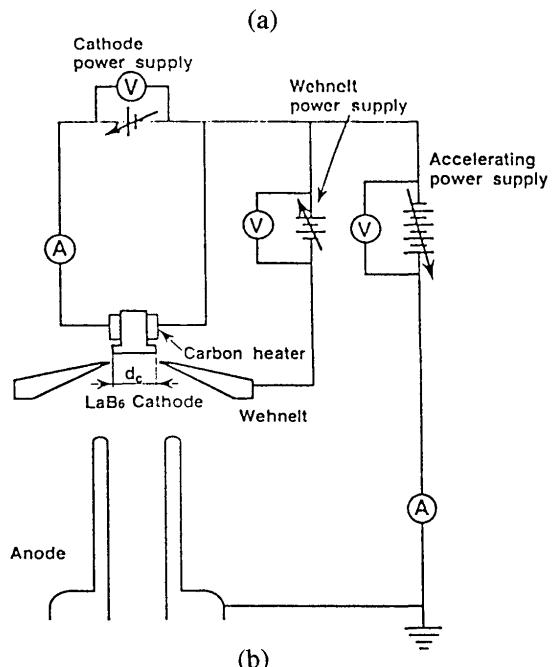
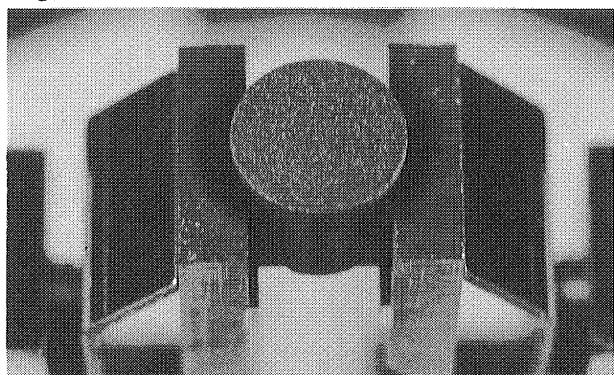


Fig. 1 (a) Directly heated type LaB<sub>6</sub> cathode and (b) Schematic diagram of circuit of gun.

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\* Associate Professor

\*\* Assistant Professor, College of Industrial Technology

\*\*\* Professor, Kinki University

## Development of $\text{LaB}_6$ Cathode for E.B.W.

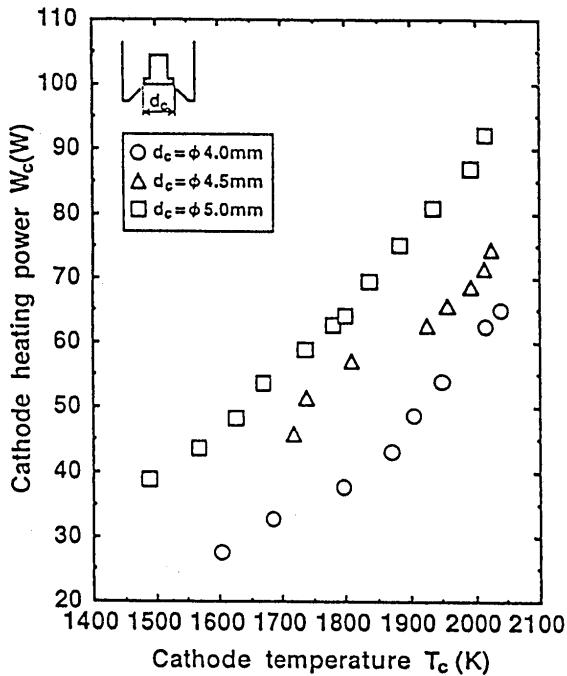


Fig. 2 Relation between heating power and cathode temperature at various cathode diameters.

The beam currents,  $I_b$ , at various beam accelerating voltages,  $V_b$ , are shown in **Fig. 3** for a 5.0 mm cathode. A high beam current is obtained with increasing cathode temperature. The beam current is 1000 mA at  $T_c=2015$  K and  $V_b=65$  kV and an output power of 65 kW is obtained. The electron gun used is a triode type with a Wehnelt electrode. Its permeance is calculated to be  $5.5 \times 10^{-8} [\text{A}/\text{V}_b^{3/2}]$  through Langmuir's 3/2 power law ( $I_b=GV_b^{3/2}$ ). At  $T_c=2015$  K, the relation of acceleration voltage and beam current follows the 3/2 power law. However, in the case of low cathode temperatures, the characteristics of a temperature limited region appear, which do not follow the 3/2 power law. Furthermore, beam current  $I_b$  was measured at various Wehnelt voltages,  $V_w$ . At  $V_b=65$  kV,  $I_b$  is 900, 700 and 500 mA and for  $V_w=200, 500$  and 900 V. It shows a good relationship between beam current and Wehnelt voltage. Wehnelt voltage for beam cut off is estimated to be about 2.5 kV.

The long-term stability of high power and high energy density electron beam generation was investigated for a 4.5 mm cathode. The beam parameter for the stability test was selected as  $I_b=300$  mA and  $V_b=60$  kV, for the requirement of 1) obtaining a fine focused beam with the magnetic lens 2) emitting a beam current for actual welding conditions 3) warming up quickly to the required beam current. The time dependence of cathode heating power  $W_c$  was measured with 10 cycles of beam on and off. The fluctuation of cathode heating power was below 5 % during a time range of 72 ks (20 hours) at  $I_b=300$  mA as shown in **Fig. 4**.

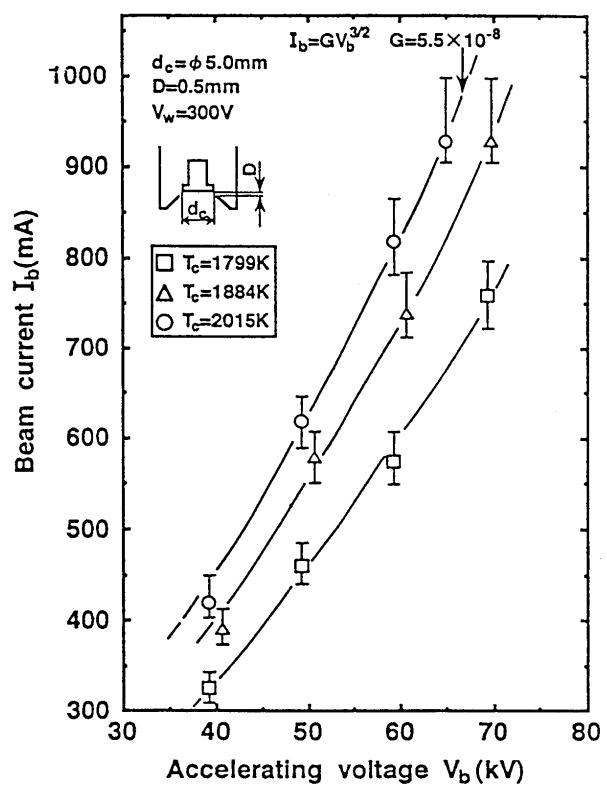


Fig. 3 Experimental result of beam current versus beam accelerating voltage. ( $d_c = 5.0$  mm)

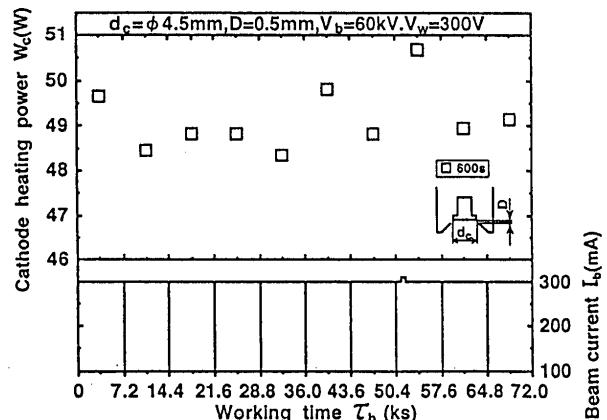


Fig. 4 Result of life time test for directly heated type cathode ( $d_c = 4.5$  mm).

Finally, the  $\text{LaB}_6$  cathode can reduce the heating power and heat distortion of the whole electron gun compared with other metal cathodes. It is shown that a stable high power electron beam is obtained for long operating times and it can thus be applied for electron guns for thermal processing.