Issues in Cathode Performance
Part 1 - Tip shape and Crystal Orientation

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LaB_6 (and CeB_6) cathodes are widely used as high-brightness cathodes in a variety of electron beam applications. These cathodes provide about 10 times the brightness and about 100 times the service life of a tungsten filament. However, to fully realize the improved brightness and lifetime of the LaB_6 (CeB_6) cathode, it must be designed and manufactured specifically for the application.

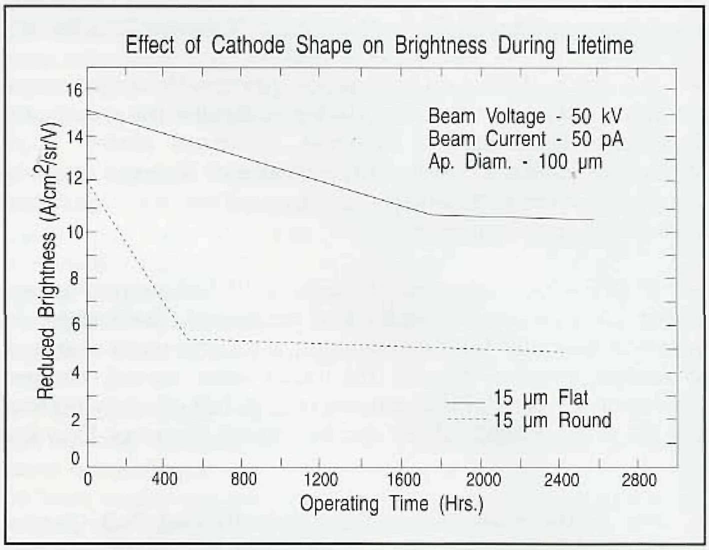
This article covers tip shape and crystal orientation. Future articles will deal with materials selection, preparation, purity, composition, and cathode operation.

LaB_6 Cathode Tip Shapes for High Performance and Long Life

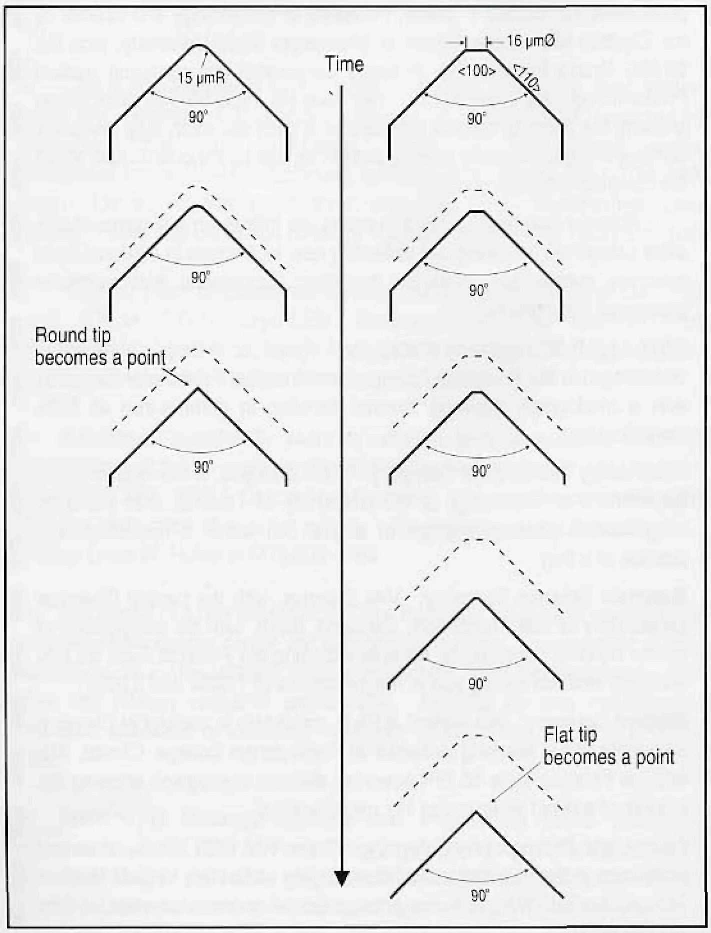
The design of the LaB_6 cathode tip is critical for *maximum* lifetime and *optimum* performance. The cathode must also provide the appropriate source size, beam current, and beam brightness for the application.

The lifetime of the LaB_6 cathode is limited by three basic factors: cathode temperature, vacuum pressure, and tip shape. The first two factors are critical and depend on proper user operation. Poor vacuum and excessive temperatures accelerate LaB_6 material loss, which decreases the cathode lifetime. The third factor, tip shape, is also critical, and careful production control ensures that the tip shape is optimized.

From our own research and that of many scientists and microscopists around the world, we have concluded that a conical tip with a flat emitting surface at the apex is the best design for optimizing performance and extending lifetime. The following figure compares how the tip shape changes as material evaporates from round-tip and flat-tip cathodes. When the cathode becomes pointed, it often can no longer produce enough brightness (amperes per cm^2 per steradian) to operate effectively. The following figure compares the drop in brightness for a rounded cathode with a 15-µm radius to a 15-µm diameter flat tip. Both cathodes are optimized for brightness at 50 kV in a JEOL JBX-5DII electron beam lithography system.



In the environment used in this experiment, a 15 µm diameter flat tip maintains a high level of brightness for up to about 2,600 hours. In the same environment, a 15 µm radius round tip has a sharp drop in brightness with about 600 hours of operation. Data acquired on a JEOL JBX-5DII by D.M. Tennant (AT&T, Holmdel, NJ) and W. Swanson (FEI Company, Hillsboro, OR)



As material is lost over time, the tip shape changes. When the tip becomes pointed, the cathode reaches the end of its useful life.

With the flat-tip cathode, it is possible to vary both the cone angle and the flat diameter to change the emission characteristics. In general, a small full cone angle (60°) results in higher brightness, but a larger angle (90°) provides longer life and easier alignment. Small flat diameters also result in higher brightness plus a smaller source size, but larger flat sizes provide longer lifetimes and more beam current. These trends allow cathodes to be tailored to the requirements of practically all thermionic cathode applications.

Scanning electron microscopy and most transmission electron microscopy applications are best served by a 90° cone and a 16-µm flat tip. This combination provides high brightness, a moderate source size, and very good lifetime, High-resolution TEM (usually 200 kV beam or higher) requires a 60° cone and a 5-µm flat tip for very high brightness and a small source size. Electron beam lithography normally requires high brightness and very stable high beam current over a long period of operation. Flat-tip sizes of 15-30 µm with a 90° cone are normally used. Scanning Auger microscopy is best served by a larger flat-tip diameter, 35 µm, for moderate resolution and high beam current.

By understanding how tip shape affects cathode performance, the best possible tip for a given instrument and application can be provided.

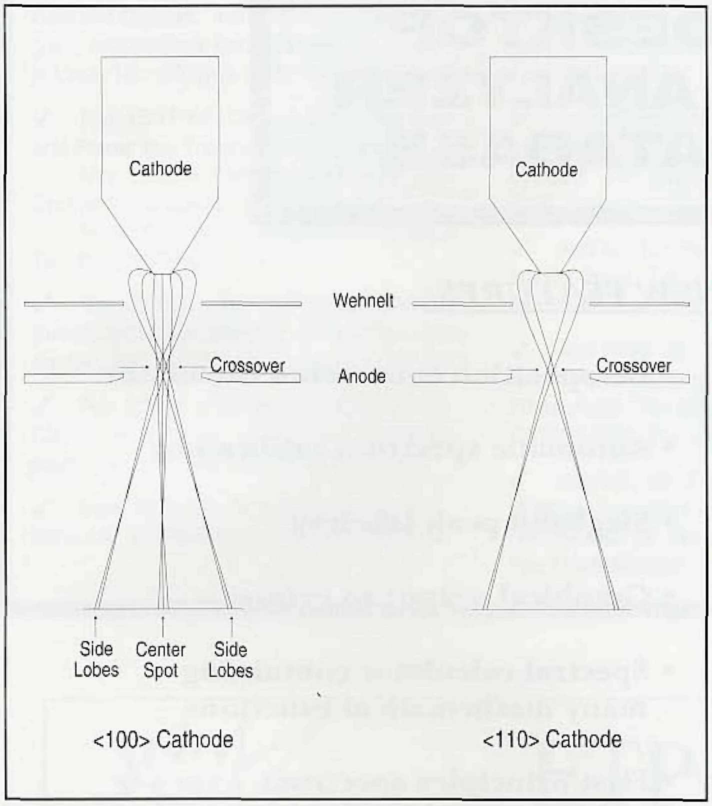
Crystal Orientation

Another consideration in the effectiveness of a LaB_6 or CeB_6 crystal as an electron emitter is crystal orientation. The <100> orientation has long been the industry standard because it meets the two major considerations: low work function and a useful emission pattern.

It is well known that higher beam brightness ultimately provides higher resolution. Achieving superior brightness depends on having a low work function orientation coincident with the emitting surface. Several crystal planes (including <100>, <210>, <310>, and <110> planes) have been repeatedly reported as having nearly equal low work functions, but the <100> plane was chosen because of its emission pattern.

For long-term operation, a cathode must maintain a bright central region in the emission pattern, which is achieved from an emission surface perpendicular to the optical axis. Additionally, it is helpful to have symmetric crystal planes about the optical axis; as the tip changes, the emission patterns arising from the exposed crystal planes remain isotropic throughout the life of the cathode. This is achieved with the <100> orientation flat-tipped crystal (see following figure).

We tested the <110> orientation to determine if crystal orientations with bright side lobes and no central spot can be effective in a modern SEM; the results were unsatisfactory. Because the <100> crystal orientation fulfills the two major crystal orientation considerations for an effective electron emitter (low work function and a useful emission pattern), the <100> crystal orientation remains the industry standard. ■



As the LaB_6 crystal evaporates during the life of the cathode, the on-axis emission surface disappears, and a central bright spot is not achievable. The best central bright spot is provide by the <100> crystal orientation.

New Book Review

Vacuum Methods in Electron Microscopy

Wilbur C. Bigelow, Department of Materials Science and Engineering, University of Michigan, Ann Arbor, MI

Series: Practical Methods in Electron Microscopy from Portland Press.
Edited by: Audrey M. Glauert

This book provides the information necessary to help scientists and engineers operate the vacuum system on the instruments they use. It starts by describing the characteristics of a vacuum and of the evacuation process.

The author goes on to explain the way the various vacuum gauges and pumps function and summarizes the operating capabilities and characteristics of these devices.

Operating procedures for several simple vacuum systems are given and six vacuum systems found on recent electron microscopes are discussed. The book finishes with a discussion of the procedures for detecting and repairing leaks in vacuum systems.

This book will be of interest to all electron microscopists as well as scientists and engineers working in other fields where vacuum systems are used on other types of scientific instruments. The author has been involved in the operation and management of electron microscopy and microprobe analysis laboratories for more than thirty years.

Contents:

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