DEVELOPMENT OF IMPROVED CATHODES FOR HIGH POWER RF SOURCES

L. Ives, G. Miram, M. Read, M. Mizuhara, Calabazas Creek Research, Inc., Saratoga, USA
Philipp Borchard, Lou Falce, Consultants
Kim Gunther, HeatWave Laboratories, Inc.

Abstract

All high power RF sources start with an electron beam generated by a cathode. The quality of this cathode directly impacts the performance of the RF device. Typically, dispenser cathodes heated to approximately 1000 C provide the electrons constituting the electron beam that is subsequently used to drive an RF circuit. A number of high power devices recently suffered significant performance degradation due to nonuniform emission from the cathode surface. Nonuniform emission can be caused by variations in termperature or work function across the cathode surface. Research is underway to determine the causes of both temperature and work function nonuniformity and derive improved construction and processing techniques and procedures to reduce of eliminate the problems. This information will be provided to cathode vendors and users to improve the future performance of these devices. This paper presents results of research to date as well as experimental measurements of cathode performance.

INTRODUCTION

High power RF sources are in development worldwide for the next generation of accelerators and colliders. Typically, RF power for accelerators is provided by klystrons. A number of novel devices are being considered, however, including gyroklystrons, multiple beam klystrons and sheet beam klystrons. Irrespective of the type RF device, the starting point for RF power production is generation of a high quality electron beam. The quality of the electron beam is determined by the optical design of the gun and the quality of the cathode. Unfortunately, RF engineers have insufficient control of cathode quality.

Most klystrons and traveling wave tubes use solid electron beams generated by Pierce-type cathodes operating space charge limited. Gyroklystrons and gyrotrons use annular electron beams created with a magnetron injection gun (MIG) operating temperature limited, which means the emission current is a function of the local temperature. Consequently, gyro device operation is more sensitive to temperature variations across the cathode surface. Efficient operation of gyrotrons and gyroklystrons require a high-quality electron beam with low-velocity spread and uniform current density around the circumference of the beam. Advances in computer modeling allow design of electron guns with velocity spreads less than 8%, which is adequate for efficient operation; however, there is substantial evidence that large azimuthal asymmetries in current emission often occur. Communications and Power Industries, Inc. (CPI), the U.S. and world leader in gyrotron production, reports azimuthal variations in the power density of the electron beam in the collector[1]. Because these devices are operating close to the thermal limit, any localized increase in the power density, such as occurs with azimuthally asymmetrical emission, can lead to overheating of the collector surface and eventual failure. Failures of this type have occurred.

The beam-RF interaction in the circuit depends on beam current, and azimuthal variations in current implies that all portions of the beam are not operating with optimal conditions, which can result in a substantial loss of efficiency. Research is underway at the University of Maryland to quantify this effect[2]. The Plasma Science and Fusion Center a the Massachusetts Institute of Technology performed experimental research on existing guns to measure the asymmetry. Asymmetries in a MIG for a coaxial gyrotron produced a 6:1 variation in current with regard to the angular position[3]. When the electron gun was replaced with one having more uniform emission (1.2:1), the output power in the gyrotron doubled.

Nonuniform temperature problems can be overcome with space charge limited cathodes by increasing the cathode temperature until all areas are operating sufficiently above the temperature limited regime. This can solve problems with nonuniform emission, however, the increased operating temperature can significantly reduce cathode life. It can also result in excessive barium evaporation to surrounding surfaces, leading to arcing.

Nonuniform cathode emission is typically caused by temperature or work function variations across the surface. Since gyro devices are more sensitive to these type variations, this program is performing detailed analysis of gyrotron cathodes to address both the temperature and work function problems. Improvements in work function uniformity will also have an impact on space charge limited cathodes, since it will allow reduction in the operating temperature.

Calabazas Creek Research, Inc. (CCR) is funded by the U.S. Department of Energy to improve the emission uniformity of magnetron injection guns for high power

RF sources for accelerator applications. CCR is addressing this effort in the following ways:

- New, innovative heater designs are under investigation to improve temperature uniformity. This includes improved geometrical design of heat shields, heater supports, potting, and surrounding thermal surfaces,

- Causes of nonuniform work function are being investigated. Once causes are determined, modifications to materials, processes, techniques, or procedures will be explored, in association with cathode manufacturers, to eliminate the causes of work function variation.

- A test facility is under construction to allow precise, detailed measurement of emission uniformity across the surface of magnetron injection guns. Precise measurement of temperature is also being developed. This will allow identification of problem areas for nondestructive or destructive analysis to identify the causes of emission uniformity or to evaluate the effectiveness of manufacturing improvements.

THERMAL DESIGN OF MIGS

Detailed, 3D thermal analysis was performed on a MIG displaying temperature variation to determine the root cause. For this cathode, the gap between the heater lead the heater coil resulted in an unacceptable temperature variation. A plot from one of the analyses is shown in Figure 1.

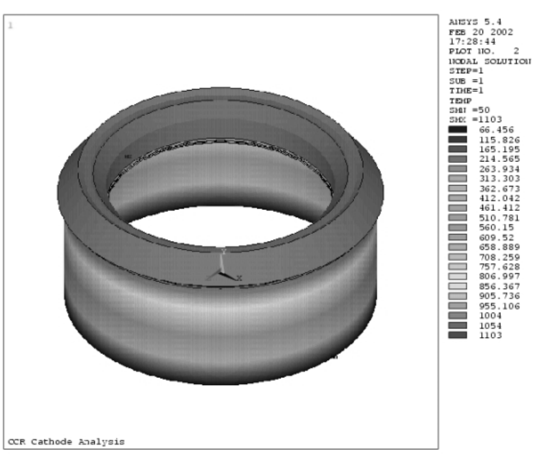

Figure 1. 3D thermal analysis of magnetron injection gun

As a result of this analysis, two improved designs were developed. The first design employs a variation in the heater winding pitch in the vicinity of the heater lead gap. The second design uses a “bombarder” cathode, where a space charge limited cathode generates an annular electron beam that heats the primary cathode by electron impact. Because the space charge limited cathode is generating little total current and operating in the space charge limited regime, it should exhibit less emission variation as a function of temperature. The uniform electron beam will then become the heating source for the primary, high current, temperature limited cathode emitter. Both these designs will be built and tested during the coming year.

WORK FUNCTION CONSIDERATIONS

The surface of a dispenser cathode typically consists of a large number of small openings on a tungsten substrate. The shape of these openings is highly irregular with random spacings. Several cathode specialists hypothesized that if the pores had a uniform shape and spacing, the barium flow and surface coverage would be uniform as well, resulting in reduced emission spread. During Phase I of this program, a cathode exhibiting nonuniform emission was donate by Communications and Power Industries, Inc. This cathode was tested in a special chamber designed to measure emission at 64 positions over the surface. The test chamber is shown in Figure 2.

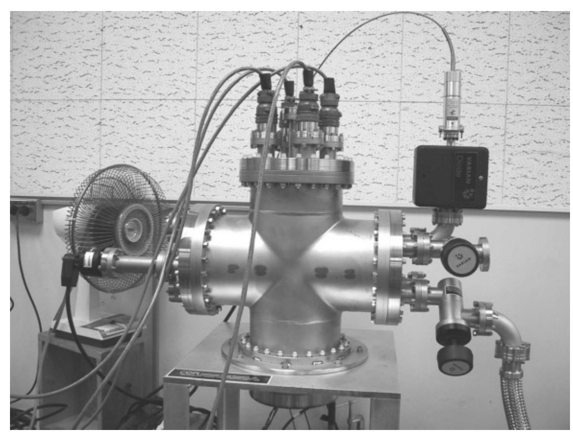

Figure 2. Test Chamber for measuring emission current

Measurements indicated that the emission was varying by a factor of two across the cathode surface. The areas of reduced emission were identified and the surface examined optically at high magnification. Figure 3 shows two regions of the surface with significantly different emission. The image on the left shows a large number of pores in a region with good emission, while the image on the right shows a region with reduced pores and emission. It would appear in this case that a variation in the pore distribution was a contributing factor to the nonuniform emission, however these results are not conclusive and additional testing is scheduled.

The research will continue to examine this cathode until a definitive cause is found for the nonuniform emission. CCR scientists and engineers will then work with the cathode vendor to address this issue in the manufacturing process.

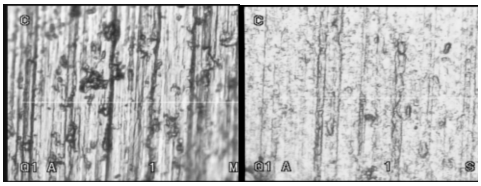

Figure 3. Magnified optical images of two regions on the cathode surface

As additional defective cathodes become available, they will also be tested. A new test chamber is currently under construction that will allow more rapid and accurate measurement of cathode emission at considerably higher resolution. A photograph of the chamber being assembled is shown in Figure 4. The chamber will include an electron beam scrubber for improved vacuum and will be adaptable to various sizes of magnetron injection guns. It is anticipated that the chamber will be available for pretesting cathodes prior to installation into tubes to avoid costly rebuilds from defective cathodes.

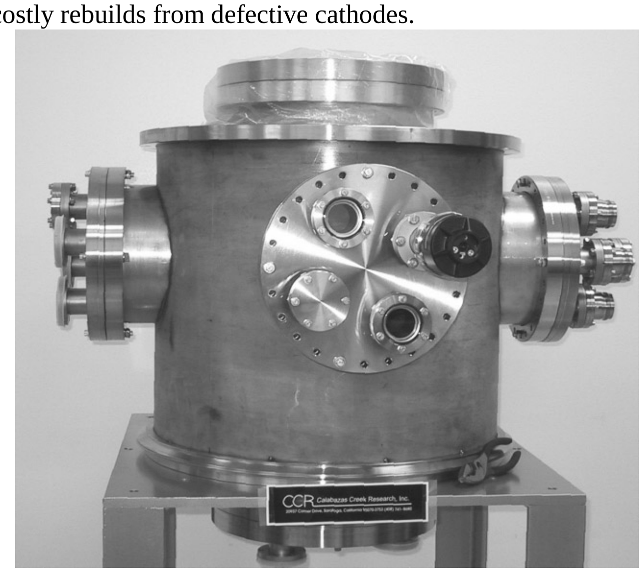

Figure 4. Test chamber for measuring emission uniformity of magnetron injection guns

SUMMARY

A research effort is underway to determine causes of nonuniform current emission in dispenser cathodes and eliminate them. The program is working primarily with magnetron injection guns operating in the temperature-limited regime. These guns are more sensitive to thermal variation than space charge limited cathodes; however, the improvements in work function uniformity will be directly applicable to space charge limited operation. Increased uniformity of the work function will allow reduction in cathode temperature with a subsequent increase in cathode life.

The program is also exploring improved designs for heaters for magnetron injection guns. Variable pitch and bombarder cathodes will be built and tested in the program. The program is also exploring improvements in heat shield configurations, potting, heater supports, cathode support, and manufacturing processes and procedures. Many of these will be applicable to both space charge limited and temperature limited cathodes.

Improve cathodes will result in improved electron beams for a wide variety of RF sources. This will ultimately result in increase efficiency, greater yield, improved performance, and lower cost for these devices.

ACKNOWLEDGEMENT

This program is supported by U.S. Department of Energy Small Business Innovation Research Grant Number DE-FG03-01ER83196.

REFERENCES

[1] K. Felch, M. Blank, P. Borchard, P. Cahalan, S. Cauffman, T.S. Chu, C. Dubrule, “Results of 10-sec Pulse Tests on a 110 GHz Gyrotron,” Intern. Vacuum Elec. Conference 2000, Monterey, CA, May 2000.

[2] Wesley Lawson, personal communication, January 2001.

[3] R. Advanti, S. Korbly, K. Kreischer, M. Shapiro, and R. Temkin, “Multi-Megawatt Gyrotrons for ECRH,” *24th Intern. Conf. Infrared & Millimeter Waves*, Monterey, CA, September 1999.