HIGH GRADIENT ACCELERATING STRUCTURE

W Gai *editor*

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Proceedings of the Symposium on the Occasion of 70th Birthday of Juwen Wang

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Preface

This special symposium was held at Tsinghua University to report on recent progress in the development of the high gradient RF accelerator and to celebrate the 70^{th} birthday of Dr. Juwen Wang. In the past several decades, Dr. Wang has made many monumental contributions to the high gradient RF accelerator studies in theory, experiments, and development of technology. We have all benefited from his wisdom and guidance, as illustrated in the papers contained within the following proceedings.

More than 50 people attended the symposium. We were especially honored with the participation and wonderful presentations of Drs. Loew and Miller. The organizing committee is very grateful for the hospitality and financial contributions from the department of Engineering Physics at Tsinghua University. We would also like to acknowledge the fine work of the conference secretary, Ms. Xue Fan, as well as that of other local services. I would also like to thank Mr. Jiahang Shao for helping me edit these proceedings.

On behalf of the organizing committee, I would like to thank all the participants for their contributions. This was a wonderful event and we wish Dr. Wang a happy birthday and best wishes in the future.

Wei Gai
Conference Proceedings Editor
Chuanxiang Tang
Symposium Chair

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Juwen Wang and High-Gradient LINACS a Celebration at Tsinghua University

Gregory Loew

SLAC National Accelerator Laboratory
Menlo Park, CA 94025, U. S. A.

1. Introduction

My report for this celebration comes in three parts:

1) Juwen Wang's early history,
2) His Ph.D. thesis,
3) His work since 1989.

2. Juwen Wang's Early History

Juwen Wang was born in Tai Kang County, He Nan Province, China on July 28th, 1943. His parents were Guozhang Wang and Yunqin Ji. He had two sisters, Juyan and Jufang, and one brother, Juwu who, after their parents' deaths, was instrumental in bringing up Juwen and supporting him. After his high school education, Juwen entered Tsinghua University for the first time in 1961. In 1968, during the Cultural Revolution, he left Tsinghua and went to work at a railway factory in Xi'an where he built electronics equipment for railways until 1978. In Xi'an, Juwen met Xiuqin Yuan and they were married on March 8th, 1973, forty years ago.

In 1978, after the Cultural Revolution, Juwen returned to Tsinghua University for a graduate degree in physics. The next year, he decided that he wanted to specialize in the field of particle accelerators. To realize his dream, he thought he would try to come to the United States of America to get a Ph.D. in this field. Somewhat by coincidence but also because of his persistence, Juwen and I met in September 1979 at an Accelerator School in Hefei to which I had been invited to give lectures.

Fig. 1. Xiuqin Yuan and Juwen Wang in 1973.

Fig. 2. Hefei was an amazing city where manual labor prevailed.

Juwen was an excellent student and he was held in high regard by his professors in China, in particular Professor Liu Naichuan. As a result, he was able to obtain a scholarship to study in the United States in 1980, and to come to work with me at SLAC. This event started a wonderful friendship and technical relationship between us.

During the first two years, Juwen did some very interesting work to measure the energy lost to longitudinal modes by single electron bunches traversing various periodic structures for linear accelerators, such as disk-loaded structures and alternating-spoke structures. This gave him some very valuable theoretical and experimental experience. As a result, he was admitted to the Ph.D. program in the Applied Physics Department at Stanford, which gave him the chance to take graduate level courses at the university and pursue a Ph.D. thesis with me.

Fig. 3. Student colleagues of Juwen Wang in Hefei, ready to learn.

3. Juwen Wang's Ph.D. Thesis

Juwen Wang's thesis became a very broad study of linear electron accelerators, covering the derivation of transient beam loading calculations in constant-gradient structures, wake field calculations and measurements, methods to shape electron bunches to obtain flat energy spectra, and detailed high-gradient breakdown studies in room temperature structures [1].

Because of the magnitude of this work, this report concentrates on the RF breakdown studies. Short of the old Kilpatrick breakdown criterion based on the effect of ion emission from cavity walls, the prevailing hypothesis at the time to explain RF breakdown was that it was caused by large electric surface fields resulting in excessive electron field emission, metal melting and damage. However, none of the details were well understood, and many experiments were needed.

In summary, what Juwen's thesis established was that:

1) Breakdown begins at relatively low field levels during RF processing and outgassing of a structure.
2) With care, the gradient can be gradually increased up to a much higher level, without damage to the structure's internal surface.
3) Eventually, a maximum gradient is reached, sparking appears on iris edges, and damage is inevitable.
4) At all field levels, electron field emission shows up in the form of dark current.
5) When breakdown occurs, the emitted current momentarily jumps up by a factor of about 40, and outgassing simultaneously increases abruptly. Then, the emitted current drops back to its steady-state value for that gradient.

Nobody knew at the time if there was an RF frequency dependence for breakdown. For this reason, experiments were carried out with several structures at different RF frequencies, as shown in Fig. 4 below. Figure 5 shows the experimental set-up, the probes and the analyzing magnet to measure the magnitude and energy of the emitted electron currents.

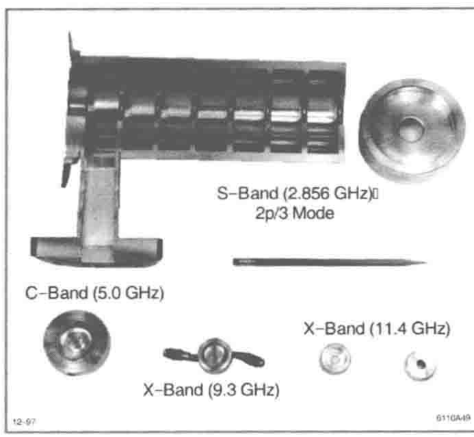

Fig. 4. Structures used to measure RF breakdown at different frequencies.

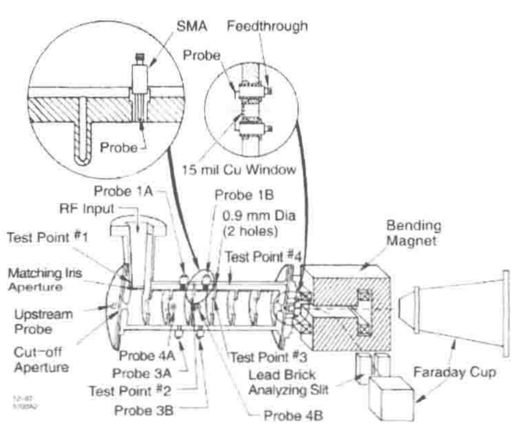

Fig. 5. Experimental set-up to measure emitted currents.

Figure 6 shows a typical set-up used to observe reflected RF signals, dark current beam spots and gas releases due to breakdown. Figure 7 shows typical gas releases during (a) steady-state operation, and (b) immediately after breakdown, where the $CO^+$and CO_2^+lines are greatly enhanced.

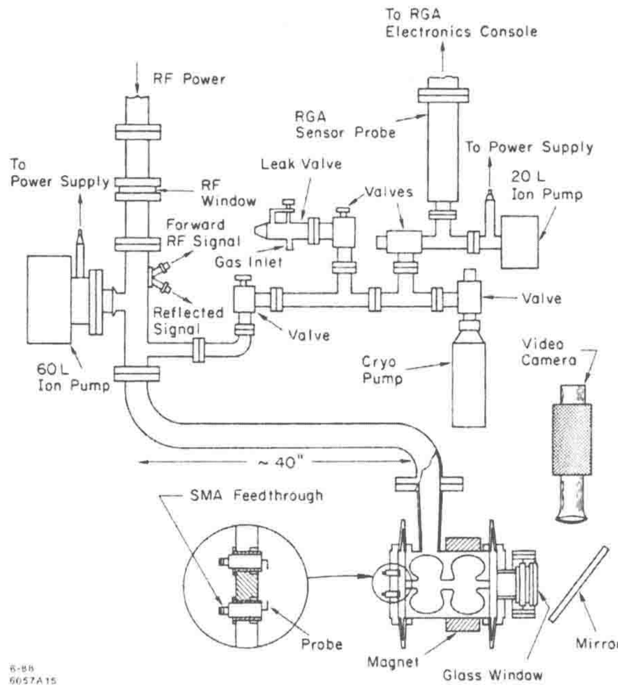

Fig. 6. Set-up to observe reflected RF signals, dark current beam spots and gas releases.

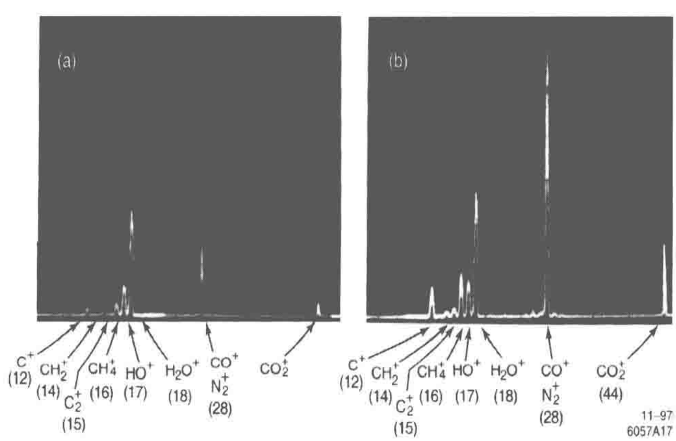

Fig. 7. Gas releases (a) in steady-state, (b) immediately after breakdown.

The surface field limits as a function of RF frequency that are shown in Fig. 8 were measured for the structures shown in Fig. 4. Note that this frequency dependence was obtained for standing-wave fields and that the filling times and RF pulse lengths available from the microwave sources were not the same for each structure. Hence, the similarity with the old Kilpatrick square-root of frequency breakdown dependence was probably purely coincidental. Also note that these field limits were attained after considerable RF processing and surface damage as shown later in Fig. 9.

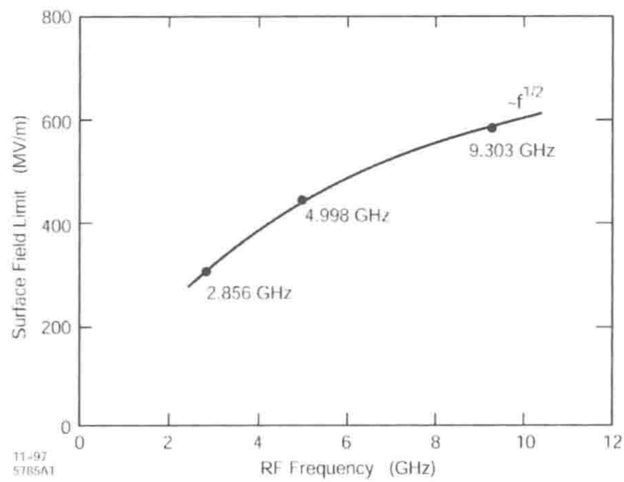

Fig. 8. Experimental surface field limits as a function of RF frequency.

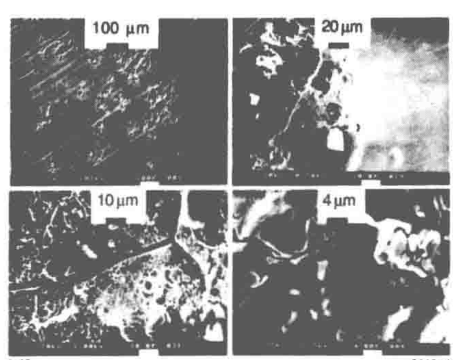

Fig. 9. S-band copper cavity wall damage after breakdown tests seen with a scanning electron microscope.

The next step in the investigation of the mechanism of RF breakdown, assuming that it was due to excessive electric surface fields, was to estimate the dependence of the field emitted current I_{FE} as a function of electric field E, surface field enhancement factor β (due to surface imperfections or impurities),