First Operation of High–Quantum Efficiency Photocathodes Inside Superconducting Cavities

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Abstract

The combination of a high–performance photocathode and a superconducting accelerator cavity promise to enable a compact injector which can deliver an extremely bright electron beam in continuous operation. But to begin with the mutual interactions of both technologies (being both extremely surface–sensitive) must be investigated experimentally. In this paper we describe the experiments which we perform to examine these interactions and present our first experimental results.

1 INTRODUCTION

In the past ten years, photoemission rf guns have been developed at several laboratories,[1] particularly for FEL applications.[2] Their capability of delivering high brightness electron beams of accurate time structure has been proven. However, they are limited to short macropulse operation due to the high electric gradient required at the cathode inside the first cavity cell.

The use of a superconducting accelerator cavity should remove this problem, enabling continuous operation at nearly the same gradient.[3] Although of great interest for several accelerator projects,[4, 5] this combination has never been tried and yet provides a technological challenge. Due to the sensitivity of superconducting cavities against additional heat load and parasitic electrons, only high–quantum efficiency photocathodes of alkali antimonide type seem to be suitable.[6] Several unwanted mechanisms degrading one of the two extremely sensitive devices can be imagined, but no data about their intensity in this environment are available: Rf heating and field emission at the photocathode due to the high rf fields at its surface, reduction of the cathode efficiency by material evaporation, by impinging ions or backaccelerated electrons, or by reaction with residual gas, and contamination of the cavity surface with cathode material causing field emission or thermal quenches.

Thus we built up an experiment to investigate these interactions in detail and to prove the feasibility of a superconducting photoemission source. To keep the experimental setup as simple as possible, no care was taken to generate a bright or even an useful beam.

2 EXPERIMENTAL SETUP

The heart of our experiment is a superconducting cavity made of high thermal conductivity niobium (Figure 1). It is shaped like a standard 3 GHz accelerator cell (Darmstadt geometry) cut half at the equator and closed with a plane plate, resulting in a basic frequency of 2.834 GHz. This shape takes into account the low initial velocity of the emitted electrons. The photocathode is located in the center of the end plate, being evaporated on top of a retractable niobium stem. It is illuminated via the beam tube by a laser emitting in the green spectral area. Actually, we use a cw He–Ne–laser with 0.5 mW light power, but the use of a higher–power pulse laser synchronized to the rf signal is in preparation.

The electron beam is accelerated into the beam tube and captured there inside an isolated coaxial inner tube which serves at the same time as rf power input coupler. Because the experiment shall not generate a bright beam, the beam dynamics parameters are not measured at all. Separated from the cavity rf signal, the beam current can easily be measured. As numerical simulations show, the extraction by the rf field is already efficient at gradients as low as 0.5 MV/m at the cathode. The rf coupling factor can be varied by moving the inner tube. At the innermost position the photocurrent can be extracted with an applied dc bias voltage and measured directly. Both dc and rf photocurrent characterize the photocathode performance under various operation conditions, being one center of our interest. On the other side, quality factor and maximum achievable field gradient characterize the performance of the superconducting cavity. Influences on these two parameters due to presence and operation of the photocathode will be the other center of our investigations. The contribution of the (semiconducting) cathode itself on the resonance quality should be low, because at this position its geometry factor is 1.2 MΩ compared to 150 Ω for the whole cavity. In addition, the cathode can be totally withdrawn enabling measurement of the bare cavity.

The retractable cathode stem must not contact the cavity surface, because an electrical spot contact would produce intolerable rf losses. Thus it is beared in a sapphire ring simultaneously providing good thermal contact. To avoid rf power extraction by the stem together with its surrounding vacuum tube, this coaxial line is blocked with a bandpass filter tuned to the cavity. The field gradients in the filter cavity are low but not negligible, thus enforcing a superconducting setup to avoid excessive heat load. The applied geometry has been proven to increase the coupling quality factor from 5×10^4 (without filter) to above 1×10^{10}. The remaining rf power behind this filter serves as monitor output.

The whole cavity with its environment is located inside a

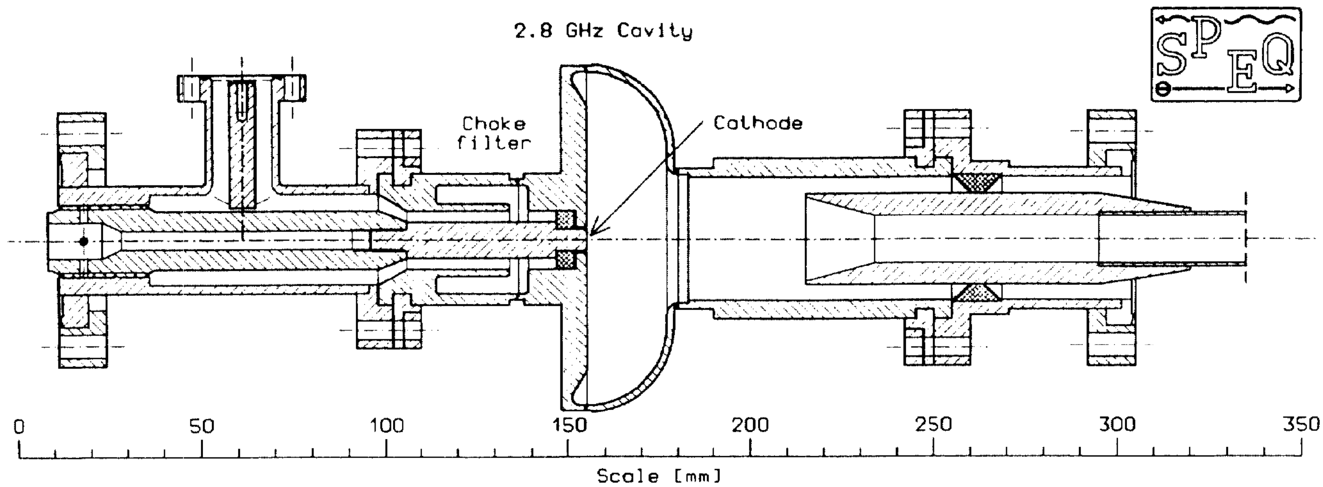

Figure 1: 2.834 GHz Superconducting Cavity Setup

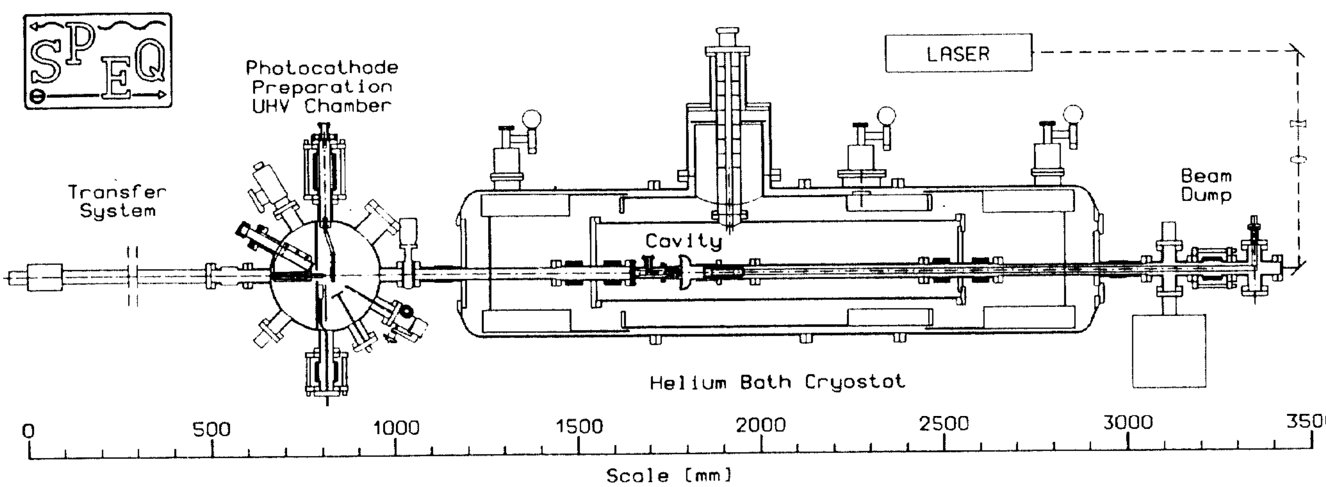

Figure 2: Complete Experimental Setup

horizontal helium bath cryostat (Figure 2), which enables operation at 4.2 K or even 1.8 K when pumped down to 20 mbar. The horizontal layout of the cryostat enables access to both beam tube and cathode stem from outside. The cathode stem can be retracted from the cavity during operation and withdrawn into a preparation chamber without leaving the vacuum environment. This preparation chamber, located directly besides the cryostat, is equipped with alkali metal (dispenser sources containing alkali chromate and reduction & getter alloy [7]) and antimony evaporation sources as well as vacuum and evaporation rate control systems. Here we use the standard preparation process for photocathodes [8] which we already tested in an independent preparation chamber [3]. There we achieved in the meantime quantum efficiencies up to 5% (at 543 nm wavelength) on Cs_3Sb being stable over weeks, and even above 8% after activation with oxygen.

3 FIRST RESULTS

The experiment described above has been completely set up in October 1991. The bandpass filter was accurately tuned to the cavity and the whole cavity then baked at 1350°C with titanium coating to improve its thermal conductivity. The preparation chamber was pumped down to 1×10^{-9} mbar, the sources tested and calibrated. A first system test of the complete setup has been done in December 1991. Although the boundary conditions in this experiment were rather poor — the cavity had a low quality factor of about 1.5×10^{7}, limiting its gradient to about 1.5 MV/m, and finally the best cathode available had a quantum efficiency of only 0.2% due to technical problems — we succeeded to insert this cathode into the cavity and to operate it there.

The cavity quality did not significantly degrade, neither by the presence nor by the operation of the photocathode (at 500 nA photocurrent). The cathode also did not limit the achievable electric field (below 1.5 MV/m). Though, we could observe processing activity during operation, linked to field emission in the cavity. The cathode showed no increased degradation with time inside the cavity when the rf field was switched off and even a significant increase in quantum efficiency during a long period operation (about one hour) at maximum field level of about 1 MV/m. We believe that this extraordinal behaviour can be explained by backaccelerated electrons (which are inavoidable with cw laser operation) somewhat improving the surface structure, and will be absent in operation with an optimized photocathode or with a pulsed laser. The cathode stem retraction system including the superconducting bandpass filter worked well. The exchange of the cathode could be performed during the cavity stayed cold.

Actually, we are improving the components which showed problems during the first test. After improvements in the preparation chamber, we could repeatedly (though not yet reliably) produce photocathodes with more than 2% quantum efficiency approaching typical design values for this type of photocathode. Also their stability was significantly increased, though not yet to the level achieved in the other chamber. The cavity has shown the same low quality in another test after firing at 850°C, thus we attribute it to titanium contamination of the inner surface. Cosequently, the cavity will be chemically etched before the next test. We avoided this treatment until now, because it also affects the performance of the bandpass filter. As soon as this is done the next test can be performed, giving for the first time the chance to measure a high-quantum efficiency cathode inside a high-quality cavity.

4 CONCLUSIONS

We have set up an experiment to investigate the mutual influences of a high-performance photocathode and a superconducting cavity housing it. This question is of particular relevance for the realisation of a superconducting photoemission source. First results prove that the cavity (with $Q = 1.5\times10^7$ and $E_C = 1.5$ MV/m) is nor affected by the presence of the photocathode neither by its operation at about 500 nA photocurrent. The Cs_3Sb photocathode can also be operated in the cold environment, and the operation of the cavity (during about one hour) does not cause a decrease of the photocathode performance. No principal limitations affecting the realization of a superconducting photoelectron source could be detected. Further experiments, aiming at better performances of both cavity and cathode, are necessary and will follow soon.

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