FEASIBILITY STUDY OF ION IMPLANTED PHOTOCATHODE FOR HIGH-BRIGHTNESS INJECTOR*

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Abstract

Our recent experimental results on the feasibility study of ion implanted photocathodes are reported in this paper. We have demonstrated the ion implantation is capable of improving the quantum efficiency(QE) of some materials, such as Cu, Ni and Al. By now cesium and potassium ions have been successfully implanted into these materials. The experiment arrangement and comparison of QE of metals with that of ion implanted metals are presented.

Introduction

Electron beam of high quality is essential to the free electron laser. Various injectors have been designed to meet this requirement. Laser-driven RF guns have been proven to be able to generate short and extremely bright electron beams [1]. The combination of photocathode and superconducting cavity can produce such electron beams in continuous operation, which is very attractive for high average power FEL [2]. A series of studies and analyses have been accomplished for the construction of a superconducting photocathode RF gun at Peking University. One of the key aspects to realize it is to choose a suitable photocathode for superconducting cavity. Several kinds of photocathodes are being studied at Peking University at present. One of them is the ion implanted photocathode.

Semiconductors and metals are both employed as photocathodes in the accelerators. The former, such as Cs_3Sb, CsK_2Sb and GaAs, has high QE, but their surfaces are very sensitive to the contamination of residual gases, as a result their life time is short. The metalcathodes are more robust than semiconductors. However their QE is 3-4 orders lower than that of semiconductor cathodes. More powerful laser has to be used to compensate their low QE. It is preferable to develop a new type of photocathode which is expected to have higher QE than metal cathode, more reliable and stable properties, and longer life time than semiconductor cathodes. Since last year, we have been engaged in a series of experiments around the studying of ion implanted photocathode. The preliminary experimental results showed that the QE has been improved after alkali ions are injected into pure metals.

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Experimental Arrangement

The preparation of ion implanted photocathode

Several kinds of metals are chosen as the implanted substrates, such as Cu, Ag, Ni, Nb and Al. At present, the cesium and potassium ions are used as implanted ions. The determination of the energy and the dose of injection are accomplished by program simulation using code TRIM90. The ion injection is carried out on a 400KV ion injector. After implantation, the cathodes are transferred through the atmosphere to a sealed vessel filled with nitrogen gas.

Photoelectric experiments

The photoelectric experiments have been conducted to measure the QE of ion implanted cathode since last year. The Cs-Cu cathode was first tested using a nanosecond pulse laser, and the QE of pure copper was measured under the same condition. From the beginning of this year, the K-Ag cathode and pure Ag cathode have been tested using another nanosecond pulse laser.

The experimental configuration is illustrated in figure 1.

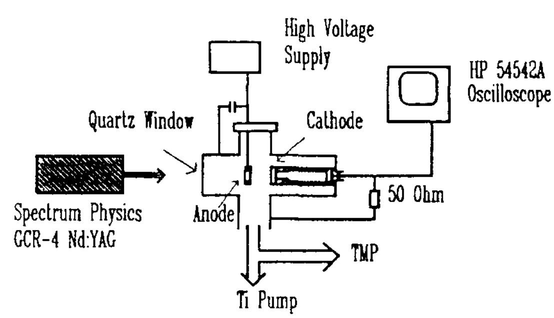

Fig. 1 Experimental configuration

It includes a coaxial target chamber, measuring electronic circuit, laser system and a high voltage supply. The system is evacuated with a turbo molecular pump and the static vacuum is kept with a titanium pump. The base pressure in the target chamber is 10^{-7}-10^{-8} torr during experiments.

The characteristics impedance of the coaxial structure is 50 Ohm, which is matched to the resistance of the sampling resistor to avoid distortion of photo-electron signals. The anode voltage must be high enough to collect all the emitted electrons from the cathode in order to overcome the space charge effect.

The cathode is activated before measurement, by laser processing and heating the cathode. Figure 2 gives the photocurrent vs. laser pulse energy for the sample of Cs-Cu under 355nm laser irradiation at different experimental stages.

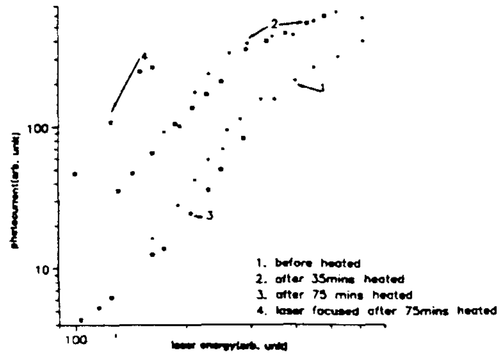

Fig. 2 Photocurrent vs. laser pulse energy with different processing. Sample: Cs-Cu. Laser: 355nm, 7ns.

Experimental results and analyses

The QE of the Cs-Cu is about one order higher than that of the pure copper under 248nm laser. The QE of Cs-Al and Cs-Ni are improved as compared with the pure metals. However, the photoelectric experiment of K-Ag does not show the improvement of QE. The QE of various samples under different experiment condition are listed in Table 1.

TABLE 1
QE of Various Samples under Different Condition

Sample	Wavelength of Light(nm)	Treatment	Qe
Cs-Cu	248	Treated	2.5E-4
Cs-Cu	248	Exposed to Air	5-7E-5
Cs-Al	532*	Before Treated	3E-6
Cs-Al	532*	After Treated	2E-4
Cs-Nb	355	After Treated	1E-9
K-Ag	266	Before Treated	2.6E-5
K-Ag	266	After Treated	1.4E-4

* Laser is focused

Discussion and Conclusions

In order to determine the concentration and depth profiling of the injected ions, the samples are analyzed with RBS. Results show that the concentration of Cs in the copper is far lower than the designed value and the implanted Cs diffuse drastically inward the substtrate. This is attributed to the spattering and enhanced diffusion effect in the period of implantation. The nanosecond laser pulse will induce unfavorable heat effect on the surface of the samples at high laser intensity. The anode voltage is limited to 8kV for test of K-Ag, which is not enough to collect all the photoelectrons, so the measured QE is lower than the actual value. The QE of K-Ag is not as good as expected, which might be caused by lack of activation of the cathode.

Among all the tested samples, Cs-Cu is the most special and interesting one with one order QE improvement. The XPS of Cs-Cu shows that the copper in Cs-Cu is in +3 valency, which is unusual considering the fact that the normal oxidation states of copper are Cu_2O and CuO. it is reasonable to contribute the noticeable QE improvement of Cs-Cu to its unique structure and electronic properties. The alkali ions in the implanted photocathodes are strongly bonded to the substrates in atomic force, as a result the contamination to superconducting cavity is less serious than semiconductors. The QE of the cathode might be even improved with higher mixing concentration. Ion Beam Mixing is planing to be employed to increase the cesium concentration in the near future.

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References

[1] C. Travier. Review of Microwave Guns. Particle Accelerators, 1991, Vol.36, pp.33-34.
[2] A. Michalke, H. Piel, C. K. Sinclair, P. Michelato. First Operation of High Quantum Efficiency Photocathodes Inside Superconducting Cavities. proceedings of the Third European Particle Accelerator Conference, 1992, Vol.2, pp.1014-1016.