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Effect of gold photocathode contamination on a flat spectral response X-ray diode

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ABSTRACT

A detector with an approximately flat spectral response is important for diagnosing intense thermal X-ray flux. A flat-spectral-response X-ray diode (FSR-XRD) utilizes a gold photocathode X-ray diode and a specially configured gold filter to give rise to a nearly flat spectral response in the photon energy range of 100–4000 eV. It has been observed that the spectral responses of several FSR-XRDs changed after a few shots of z-pinch experiments on the Primary Test Stand facility. This paper presents an analysis of the changes by fitting the spectral responses of the gold photocathodes using a model with a free parameter which characterizes the thickness of the contamination. The spectral responses of FSR-XRDs were calibrated with synchrotron radiation, and several cleaning methods were tested with the calibration. Considering the results of model and cleaning, it may be anticipated that contamination was the major reason of the response changing. Contamination worsened the flatness of the spectral response of the FSR-XRD and decreased the averaged response, hence it is important to avoid contamination. Current results indicate a requirement of further study of the contamination.

1. Introduction

There are various ways to diagnose soft X-ray flux [1–4]. In diagnosing thermal X-ray flux, which is produced by a large scale laser [5–7] or pulsed power [8] facility, only a few detectors are available because the flux is so intense. Meanwhile, intense thermal X-ray flux is important to many high energy density physics studies, such as indirect driven inertial confinement fusion (ICF) [5,6,8], radiation transfer [9] study, opacity measurements [10] and many other experiments [11] for benchmarking astrophysical material properties. Since the spectrum is either unknown or complicated, a lot of researches have been developing a detector with an approximately flat spectral response [12–15], which has an advantage that the signal is proportional to the X-ray power regardless of the source spectrum. On the Shenguang-III prototype laser facility [15] and the Primary Test Stand (PTS) pulsed power facility [16–18], a type of flat-spectral-response- (FSR-) X-ray diode(XRD) is used because of its suitable response, small size and relatively simple structure. PTS is a 20 TW pulsed power driver constructed by the China Academy of Engineering Physics for z-pinch study. The system is able to deliver a current of about 8 MA with about 70 ns rise time (10% – 90%) to a z-pinch load.

The FSR-XRD utilizes a gold photocathode XRD and a specially configured gold filter. The spectral responses of the two components give rise to a nearly flat spectral response in the photon energy range of 100–4000 eV. Depending on the surface condition of the photocathode, the response of the XRD sometimes changes, which is normally interpreted as an aging effect [19–21]. It could be caused by various reasons, including contamination, physical damage from debris and the changes induced by radiation in the surface of the material [22].

This paper presents changes of FSR-XRDs in z-pinch experiments [23] which were performed on the PTS. The spectral responses of gold photocathodes and the filters were calibrated with synchrotron radiation at Beijing Synchrotron Radiation Facility (BSRF) [17,18,24,25]. After used in z-pinch experiments, the filters exhibited unchanged transmissions, while the gold photocathodes exhibited changed responses. A model was developed to analyze the change of the spectral responses of the photocathodes. Wherein, primary [26] and secondary electron emissions [26–28] of gold were considered with an energy conservation relation. When a blocking effect and a self emission effect of contamination were considered, spectral responses of both newly fabricated and used photocathodes could be fitted by the model with a free parameter which characterized the thickness of the contamination. Moreover, as

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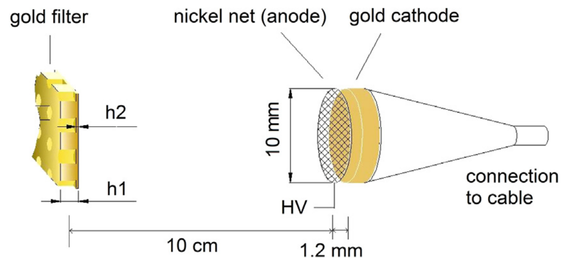

Fig. 1. The specially configured gold filter, nickel anode and gold photocathode of FSR-XRD.

mentioned later, the above two effects were observed to be reduced after some cleaning procedures, hence contamination may be anticipated to be the major reason of the change of the spectral responses. As illustrated later, the contamination worsens the flatness of the spectral response and decreases the averaged response, therefore it is better to be avoided.

The foregoing part is an introduction. Section 2 is a brief description of the FSR-XRD and the changes of its response in z-pinch experiments. Wherein, setup of FSR-XRD in z-pinch experiments and calibrations of photocathodes and filters are presented. Section 3 illustrates the model which describes the spectral response of a contaminated gold photocathode. Fitted results are presented in Section 4, then the effect of contamination on the total spectral responses of FSR-XRDs is presented. Section 5 illustrates results of several cleaning methods. Section 6 discusses possible sources of contamination in z-pinch experiments. The paper is concluded in Section 7.

2. FSR-XRD and the change of its response

2.1. FSR-XRD and its spectral response

In a FSR-XRD, a gold cathode XRD is paired with a specially configured gold filter. The XRD was designed by Wang et al. [29], and the gold filter was designed by Li et al. [15].

Regardless the complicated electrical structure for a fast response (~ 150 ps), the XRD could be considered as a photocathode and an electron collector. A mesh of nickel wires with a transparency of about 90% is used as the electron collector which is placed in front of the cathode and biased to a high voltage (HV) of 2000–2500 V (as illustrated in the right part of Fig. 1). Through the fine mesh, soft X-ray is incident on the gold photocathode normally. Hence the spectral response of a XRD is about 90% of the photocathode's spectral response.

The filter of FSR-XRD has a microstructure as illustrated in the left part of Fig. 1. It has shallow holes in every l, which is typically 11 μm. The thickness of gold around holes is h_1 and the thickness of gold in the bottom of a hole is h_2, where h_1 and h_2 are two tunable parameters. Transmission of the filter satisfies the following equation,

$$t_{filter}(E) = (1-a)e^{-h_1\mu(E)\rho} + ae^{-h_2\mu(E)\rho}, \quad (1)$$

where E is the energy of the incident X-ray, a is the ratio of the area of holes to the total area of the filter, ρ is the density of gold, and $\mu(E)$ is the mass absorption coefficient of gold. The parameters h_1, h_2 and a are important to the flatness of the spectral response of a FSR-XRD.

The gold of photocathode was evaporated on a cooper base or an aluminum alloy base with a thickness of a few micrometer. Most of soft X-ray is absorbed in gold by photoelectric effect; however, the induced photo-electrons and Auger electrons, which are the so called primary electrons, do not contribute too much to the XRD signal [26]. For example, in the photon energy range of < 1500 keV, they contribute less than 20% of the total signal. On the contrary, low energy electrons dominate the signal, which are the so called secondary electrons [26–28]. In the energy region we considered (< 5000 eV), the mean free paths of both the primary electrons and the secondary electrons are much less than the thickness of gold, hence the base does no contribute to the response. Considering contamination, it is much more complicated. Details of the response of a contaminated gold photocathode will be presented in the next section, where the model of the spectral response is presented.

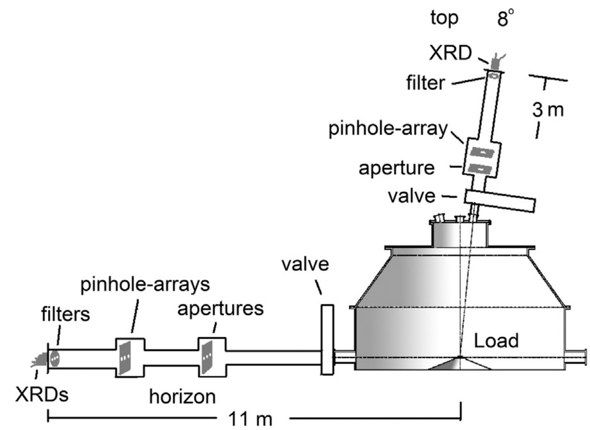

Fig. 2. Apparatus of FSR-XRDs in z-pinch experiments. The filters were mounted in the vacuum pipelines. The meshes and the photocathodes were accommodated in shells of XRDs, which were mounted on openings of the tails of the pipelines.

The total spectral response of a FSR-XRD is a multiplication of the XRD's spectral response and the filter's transmission.

2.2. Setups in z-pinch experiments

A continuous series of z-pinch experiments was performed on the PTS. In these experiments, a z-pinch radiated thermal X-rays with a peak temperature of about 140 eV [23], while the peak of the spectrum was over 400 eV.

The load of a z-pinch experiment was located in the center of a vacuum chamber which was a nearly half sphere of about 3 m in diameter plus a cylinder of about 3 m in diameter and about 5 m in height. Diagnostics were mounted on the half sphere which was empty inside, and the cylinder accommodated magnetically insulated transmission lines(MITL) [16] which delivered the driven current, as illustrated in Fig. 2.

In both horizon and top directions, two vacuum pipelines were used to mount FSR-XRDs in the distances of about 11 m and 3 m, which ensures line of sights (LOS) in the radial and in the axial, respectively. Three FSR-XRDs were mounted in the horizon pipeline and one FSR-XRD was mounted in the top pipeline. For each FSR-XRD, the gold filter was mounted on an aluminum slab in front of XRD with a distance of about 10 cm. In each pipeline, there were two other slabs in the middle, one was attended with an aperture (apertures) to collimate and another was used to mount a pinhole array (pinhole arrays), which was used to reduce X-ray flux and to protect the detector. The effect of reducing X-ray flux has been discussed elsewhere [17]. The protection to detector was obvious since sometimes very small debris was observed on the pinhole array, and less damages of the filters were observed. Since the XRDs were behind gold filters, the effect of debris on XRD was negligible.

In order to keep a condition as clean as we can, the pipelines had their own vacuum systems. Valves in the pipelines were closed before mounting the FSR-XRDs. Each pipeline was pumped with a turbomolecular pump (5 L/s pumping speed, manufactured by KYKY Technology Co., LTD) after mounting the FSR-XRDs. The valves were opened several minutes before shot, while the vacuum of chamber was better than 8×10^{-3} Pa. After several minutes of the shot, the valves were closed again.