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The beam coherence simulation of 1-dimensional nano-scale photocathode under high power laser irradiation

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Abstract

1-dimensional (1D) nano-scale photocathode with back-illumination is a promising technology for producing highly coherent electrons which may allow us to realize 4-dimensional space-time analysis of atomic structures. By simulation, we evaluated the coherence of electrons generated from gold cathode by taking into account laser-induced heating effect. The laser irradiation conditions for different cathode thickness were derived from 1D-Two Temperature Model (TTM). We also investigated the coherence of the beam by beam tracking simulation including conventional extracting electric field. Our result indicates that the beam coherence at the acceleration electron where the sample to measure is located is not sensitive to the initial beam coherence on the cathode surface.

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Keywords: photocathode, two-temperature model, coherence, emittance;

1. Introduction

Over the last several decades, a wide variety of physical, chemical and biological processes in ultra-short time scales and angstrom space scale has been the subject of much discussion and research [1, 2, 3]. Observations of

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these structural dynamics, provided by time-resolved x-rays or electron diffractometers, have revealed the processes such as phase transitions [4], chemical reactions [5], and laser ablation [6]. The electron diffraction, as compared to time-resolved x-rays, is considered to have two advantages; (1) the instrument can be built as a compact, table-top device, and (2) the basic process of elastic scattering of electrons has a cross section much larger than x-rays by 5 orders of magnitude [7] for producing diffraction signals. For these reasons, electron diffractometer is often used as the preferred method in some of these studies. The electron diffraction provides temporal and space resolution with 100 fs (femtosecond) and sub-angstrom. While its temporal resolution is anticipated to reach a femtosecond scale by employing RF compressors [8] and single electron pulses [9], improvement of its special resolution in wider view areas is subject to issues associated with aberrations and cathode performance. Chromatic aberration can be reduced by matching the photon energy and cathode work function, and spherical aberration is suppressed by removing electric and magnetic lenses [9]. As we discuss later, by employing two-photon photoemission, the cathode diameter can be optimized for producing highly coherent electrons [10, 11]. Electron pulses from plane-shaped photocathode has an advantage with high temporal resolution, up to 100 fs. However, its lack of transverse coherent length limits the observable object region. Many chemical and biological molecules of complex structures have sizes of a few 100 nm. Thus, to obtain accurate and complex diffraction patterns from such samples, the next-generation ultrafast electron diffraction (UED) devices will need ultrashort electron pulse with a transverse coherent length exceeding 100 nm with a non-distortive wave-front. To generate such high quality beams, we need to correctly evaluate the beam coherence.

The transverse coherent length ξ of an electron beam is defined as follows:

$$\xi = \frac{h}{m_0 c}\frac{w}{2\varepsilon}, \tag{1}$$

where h is the Planck constant, m_0 is the electron mass , c is the speed of light, w is the beam size, and ε is the intrinsic emittance. The coherent lengths of the beam at the cathode and at the sample to be measured are, when space-charge effects can be ignored, related as follows:

$$\xi_{sample} = \xi_{initial}\frac{w_{sample}}{w_{initial}}, \tag{2}$$

where w_{sample}, $w_{initial}$, ξ_{sample}, and $\xi_{initial}$ represent the beam coherence and the width at the sample and at the cathode, respectively. The equation (2) indicates that the transverse coherent length grows as the beam travels in a free drift space. Requirement for a large ξ_{sample} generally means requirement for a small $w_{initial}$. In the non-flexibility configuration between the cathode and the sample such as lens-less imaging regime, beam size at the cathode is required as small as possible. However, the optimized focusing beam may leads to the intrinsic emittance growth.

The work in [9] and [12] report that the transverse coherent length at a photocathode plate with UV laser excitation is 2-3 nm [9, 12]. Kirchner et al also report that with single electron emission the transverse coherent length of 20nm has been obtained, and that it may eventually reach 100 nm [11]. The work of [14] reports that a smaller electron emission area leads to the higher transverse coherent.

In fact, ξ_{sample} differ from initial one at least one order of the longer coherent length under the lens-less imaging regime, and most of the initial coherence is determined by contributions from the initial excitation state and the transition process in the bulk of cathode materials. However, $\xi_{initial}$ is worsened by the laser irradiation disturbance, and it is unknown that how the coherence value is effective from the laser quantitatively.

In particular, it is important for two-photon photoemission, which employs high intensity around 10^{10}W/cm^2, to be preferred as a UED photocathode for ease of experimental optimization. There is the high order dependence in the emission yield of nonlinear photoemission, which provide the optimization focus length for high transverse coherent length [10, 13]. For achieving the quality of coherence as higher as possible, we simulate the initial coherence including laser heating effect.

This work is done as follows: Firstly, we calculate electron temperature using two-temperature model (TTM) for ultrafast pulse laser. Secondly, taking into account the calculated electron temperature, we evaluate intrinsic emittance and transverse coherent length at cathode. Finally, the beam tracking simulation in the lens-less imaging system was carried out, which including calculated initial coherence, the transverse coherent length at the sample is evaluated.