CHAPTER 1

Introduction

In a present day, many scientific institutes or laboratories have developed particle accelerators in order to use as powerful tools, which can be applied in scientific researches and applications in many fields. Particle beams produced from accelerators can be directly used or utilized the source of radiation. One of the famous kinds of accelerator-based light source is a free-electron laser (FEL) [1]. The FEL has an important advantage over the conventional lasers that the FEL wavelength does not depend on the binding energy of the atom. Therefore, its wavelength is tunable. To generate the FEL, an electron beam with low energy spread and small emittance is transported through a magnetic field of a special magnet called undulator magnet. The undulator magnet consists of periodic dipole magnets, which are arranged perpendicular to the electron beam trajectory. The undulator magnetic field can be described by [2]

$$\vec{B} = B_0 sin(\frac{2\pi z}{\lambda_u})\hat{y} , \tag{1.1}$$

where B_0 is the peak magnetic field and λ_u is the period length of the undulator. As an example, the periodic vertical magnetic field of the undulator magnet forces electrons to move along a sinusoidal path in the horizontal plane as shown in Fig. 1.1 and the electrons emit the electromagnetic radiation with a fundamental harmonic wavelength of

$$\lambda = \frac{\lambda_u}{2\gamma^2}(1 + \frac{K^2}{2} + \theta^2\gamma^2) , \tag{1.2}$$

where γ is the Lorentz factor, K is the undulator parameter and θ is the opening angle of the radiation cone [3]. The undulator parameter K indicates the strength of the undulator magnet and it depends on the magnetic field intensity (B_0) and the undulator period as

$$K = \frac{eB_o\lambda_u}{2\pi mc} , \tag{1.3}$$

where e is the electron charge, m is the electron mass and c is the velocity of light in vacuum. According to equation (1.2), the radiation wavelength can be varied by adjusting the electron energy, the period length or the magnetic field of the undulator magnet.

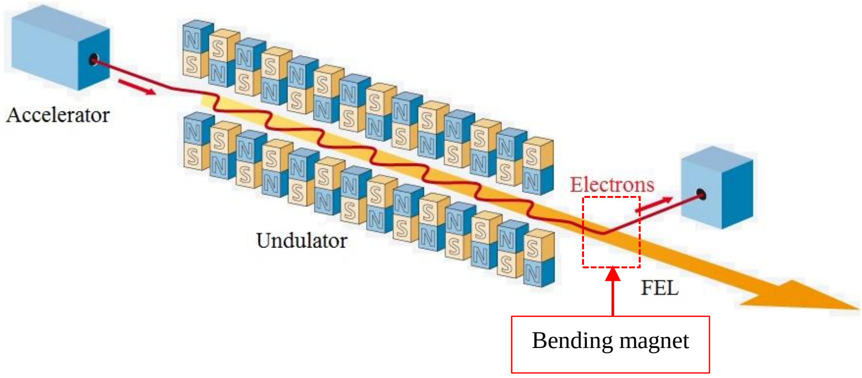

Figure 1.1: Diagram illustrates a moving path of electrons inside the undulator magnet [4].

Important electron beam properties to be considered in the generation of the FELs are a beam peak current, which depends on a bunch charge and bunch length, an average energy, an energy spread and a transverse beam emittance. The quality of the electron beam can be determined by a brightness of the beam, which is defined as [5]

$$B_n = \frac{2I}{\pi^2 \varepsilon_{(n,x)} \varepsilon_{(n,y)}}, \tag{1.4}$$

where I is the beam peak current, while $\varepsilon_{(n,x)}$ and $\varepsilon_{(n,y)}$ are the normalized horizontal and vertical beam emittance values, respectively. As shown in equation (1.2) that the wavelength of the undulator radiation depends on the beam energy, while the qualities of radiation depend on the beam brightness. The electron beam with a short bunch length and a small energy spread emits the coherent radiation with a narrow energy bandwidth. Moreover, the beam with a high peak current and a small emittance value emits the radiation with high intensity.

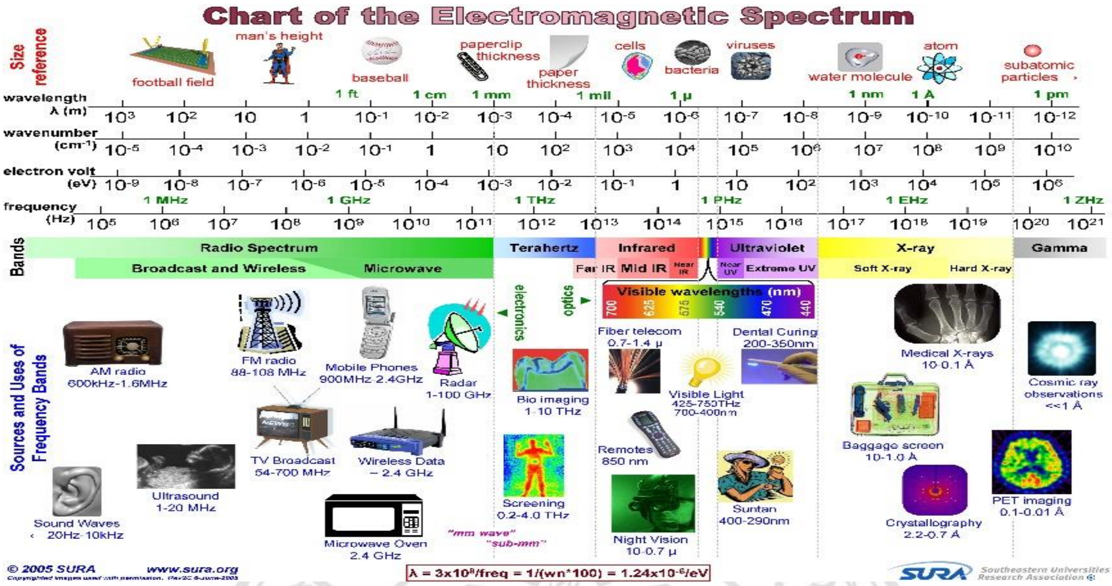

Figure 1.2: Diagram of electromagnetic spectrum [6].

The FEL can be generated in wide radiation wavelengths in the electromagnetic spectrum, which is shown in Fig. 1.2, from infrared, visible light, ultraviolet and X-ray. There are two most popular FEL radiation wavelengths, which are infrared (IR) radiation and X-ray. The infrared radiation can be divided into three main regions, which are near-infrared (NIR), mid-infrared (MIR) and far-infrared (FIR). The FIR radiation in the region of terahertz (THz) radiation with the frequency from 100 GHz to 10 THz or the wavelength of 30 μm to 0.3 mm has special properties, which can be absorbed by water, reflected by metals and penetrate through organic materials such as clothes, woods, plastics, ceramics and papers. Thus, it can be used in a non-destructive detection of goods, explosive and pharmacological materials inside the package [7, 8]. Due to these essential features, developments of free-electron laser light sources in the THz regime are currently ongoing in several laboratories world-wide.

At the Institute of Advanced Energy (IAE), Kyoto University, Uji campus, Kyoto, Japan, a compact accelerator for generation of the THz-FEL is developed [9]. The system consists of a 1.6 cell BNL type S-Band photocathode RF-gun, a chicane magnetic bunch compressor, triplet quadrupole magnets and a short planar undulator. A conceptual diagram of the accelerator is shown in Fig. 1.3. In May 2015, the photocathode RF-gun succeeded to generate the first electron beam via the photoelectric effect.

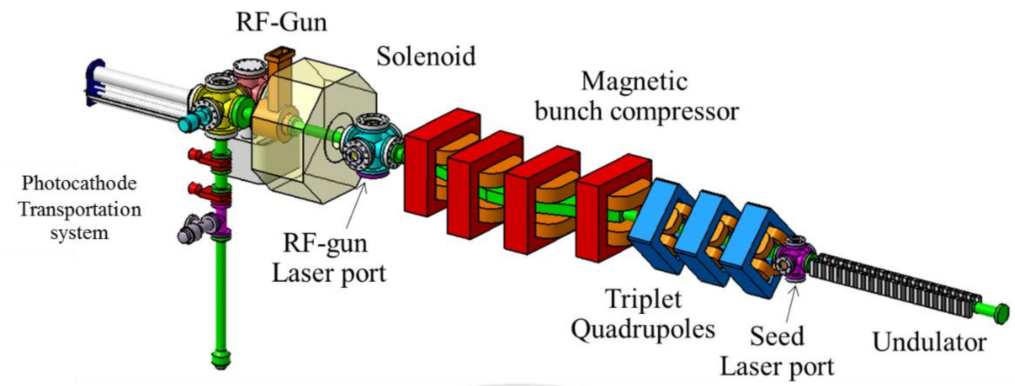

Figure 1.3: Conceptual diagram of the compact accelerator for generation of the THz-FEL at Kyoto University [9].

The research program in this thesis concentrates on study of generation and measurements of electron beams produced from the photocathode RF-gun. All measurements presented in this thesis were performed at the Institute of Advanced Energy (IAE). Production and acceleration of electrons inside the RF-gun depend significantly on the drive laser property and the RF wave condition. In order to ensure that all elements in the system work properly, the properties of a solenoid magnet, a dipole magnet and quadrupole magnets were studied. The beam diagnostic instruments were developed and installed in the accelerator beam line downstream the RF-gun for the measurements of the electron beam properties. Electron bunch charge measurements were performed by using a Faraday cup. Beam energy measurements were done by using a combination of dipole magnet and a fluorescent screen. Beam emittance measurements were conducted with the quadrupole scan method using a thin lens approximation. Some measurement data are compared with the results from beam dynamic simulations using the program PARMELA [10]. The simulations were done during the measurement period at Kyoto University and after the detailed measurement data analysis at the Plasma and Beam Physics Research Facility, Department of Physics and Materials Science, Faculty of Science, Chiang Mai University, Thailand. The results of both beam measurements and simulations can be used as the useful information for improvement of the electron beam production from the photocathode RF-gun.

The contents in this thesis is divided into 5 chapters. The first chapter introduces the background, motivation, objectives, overview and usefulness of the research. The second chapter contains the related theory and principles, which are electron production by using the photoelectric effect, electron acceleration by using a radio-frequency (RF) wave, the bending and focusing of the electron beam by using the magnetic field of the dipole and the quadrupole magnets, the space charge effect, which can influence on both beam energy and beam emittance, and the stopping power of materials, in order to explain about the charge loss and the beam energy reduction while the electron beam hits the vacuum window. Chapter 3 focuses on the methodology including production of photoelectrons, acceleration of electron in the RF-gun, electron beam focusing as well as measurements of electron bunch charge, average energy and transverse emittance. Chapter 4 presents and discusses the results from measurements and simulations. In the last chapter, all study results are concluded and discussed. Some suggestions for the future works are also presented at the end of this chapter.