# SURIYA electron beam program of Thailand Center of Excellence in Physics

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*The Thailand Center of Excellence in Physics is an organization under the Ministry of Education aiming at promoting physics research in local Thai universities. Particle beam and plasma physics is one of the emphatic fields to support. The SURIYA electron beam program has been one of the objectives supported. The SURIYA electron beam facility installed in Chiang Mai University has been developed for more than a decade to produce femtosecond electron bunches and THz radiation. The 10-m-long facility consists of a radio-frequency (RF) electron gun, an alpha magnet, a 20-MeV linac, 9 quadrupole magnets, 3 transition and parametric X-ray radiation experimental stations, and a dipole magnet, etc. The RF gun working with a frequency of 2856 MHz produces electron bunches of 20-30 ps which are further compressed in the alpha magnet. The linac is of a SLAC (Stanford Linear Accelerator Center) type. At the experimental stations, the bunches are compressed to less than 1 ps. The femtosecond electron bunches are used to generate intense THz or far-infrared radiation in the form of coherent radiation. Such radiation is of great interest for THz spectroscopy and THz imaging applications. THz spectroscopy experiments, especially those on highly absorbing substances, using coherent THz transition radiation sources and DFTS (dispersive Fourier transform spectroscopy) techniques, have been conducted. It is possible to extend the spectral range further by using shorter electron bunches. The paper provides details of the SURIYA facility, techniques, applications in THz imaging and recent new development in equipment upgrading and exploring linac-based Infrared Free-electron Laser (IR-FEL) technology.*

***Програмата за електроннолъчеви технологии на SURIYA на тайландския Център за високи постижения във физиката (Ч. Тонгбей, С. Суфакул, Дж. Сейсут, Л. Ю, Т. Вилатонг).*** *В Тайланд Центърът за високи постижения във физиката е организация, в рамките на Министерството на образованието, насочена към насърчаване на физическите изследвания в местни тайландски университети. Физиката на снопове от ускорени частици и физиката на плазмата е една от категорично подкрепяните направления. Програмата за електроннолъчеви технологии на SURIYA е една от поддържаните цели. Електроннолъчевото съоръжение на SURIYA, инсталирано в университета Chiang Mai, е разработено за повече от десетилетие, за да произведе фемтосекундни електронни пакети от импулси и THz радиация. 10 метровото съоръжение се състои от радиочестотна (RF) електронна пушка, алфа магнит, 20-MeV линеен ускорител, 9 квадруполни магнити, 3 преходни и параметричен рентгенови експериментални станции, диполен магнит и т.н. Радиочестотната електронна пушка работи с честота от 2856 MHz произвежда електрони импулсни пакети от 20-30 ps, които са допълнително компресирани в алфа магнит. Ускорителя е тип SLAC (Stanford Linear Accelerator Center). На експерименталните станции, импулсните пакети са компресирани до по-малко от 1 ps. Фемтосекундните електронни импулсни пакети са използвани за генериране на интензивна THz радиация или кохерентна радиация далечната инфрачервена област. Такава радиация е от голям интерес за THz спектроскопия и THz образни приложения. Провеждат се THz спектроскопски експерименти, особено тези на силно абсорбиращи вещества, използващи съгласувани THz преходни радиационни източници и техники за спектроскопия, базирани на дисперсно преобразуване на Фурие (DFTS). Възможно е да се разшири допълнително спектралния диапазон с помощта на по-къси електронни пакети от импулси. Статията дава подробности за съоръжението SURIYA, техники, приложения за THz изображения и скорошно ново строителство за модернизация на оборудването и проучване на базирана на линейни ускорители инфрачервена със свободни електрони лазерна технология (IR-FEL - Infrared Free-electron Laser).*

## Introduction

Thailand started electron linear accelerator technology about three decades ago. But, at that time, almost all facilities were installed in hospitals for medical therapy and sterilization. About 1.5 decades ago, electron linear accelerators were developed for physics research and industrial applications. One of these accelerator projects was named as SURIYA, which in Thai means the sun or God of light, actually following the electron linear accelerator facility's name, SUNSHINE, at Stanford University, USA, as the SUNSHINE facility was decommissioned in 2002 and many parts of it were then transferred to Chiang Mai University (CMU), Thailand. Since development of high-brightness electron beams has been a key and critical issue in the success of most electron accelerator projects, the SURIYA facility was in fact designed to reach even shorter electron bunches of 50 femtosecond (fs) than that of 120 fs of the SUNSHINE facility at Stanford. Production of such short femtosecond electron pulses can provide many opportunities for research tools which are not available elsewhere. Work on extremely fast processes like chemical reactions occurring at sub-picosecond timescales can open up new and exciting ways to study the dynamics of materials in physics, chemistry and biology. Some possible applications which can be pursued at SURIYA may include generation of low energy electron pulses for direct application, production of coherent, high intensity far infrared radiation, and generation of femtosecond X-ray pulses for various materials characterizations. Femtosecond electron pulses at low energies of a few MeV were applied by the Nobel laureate A. Zeweil to study the dynamics of chemical transitions [1]. At the SURIYA facility such femtosecond electron pulses can be produced at much higher intensity. It will be possible not only to reproduce such experiments, but also to expand on its capabilities. Production of coherent, high intensity far infrared radiation allows the probing of chemical and biological samples in dilute watery solutions which is not possible otherwise. The effectiveness of this radiation together with Dispersive Fourier Transform Spectroscopy to study, for example, Hydrogen-Bond-Stretching-Modes in DNA was demonstrated [2]. Low-frequency vibrations play important roles in biological functions. Such vibrations are biologically important since they involve motions of large groups of atoms relative to each other. These motions can be important for conformational transitions associated with biological functions, such as the local "melting" (i.e. the separation of the two strands of DNA) of the DNA double helix during transcription and the transport of molecules and ions through the cellular membrane by membrane transport proteins. The SURIYA facility can be the only radiation source intense enough to study such dynamics in the country. Femtosecond X-ray pulses are of great importance for chemistry and biology [3, 4] because atomic reactions occur at timescales of less than a picosecond. Femtosecond X-ray pulses are required to probe the dynamic of chemical and biological processes. When an electron passes through a crystal, hard X-ray radiation is produced by the Smith-Purcell process. The duration of such X-ray pulses is the same as that of the femtosecond electron pulses.

Since the SURIYA project was launched as a national program, it has been vigorously and steadily developed for femto science and technology in the country. The Thailand Center of Excellence in Physics (ThEP Center) is an organization under the Ministry of Education aiming at promoting high-quality physics research in local Thai universities. Particle beam and plasma physics is one of the emphatic fields to support. The SURIYA electron beam program has been one of the objectives under significant supports and concerns. Some of the researchers and administrators of ThEP Center have also been participating in the management and research work of the SURIYA program.

## Facility Development

Fig. 1 shows a schematic diagram of the SURIYA facility at Chiang Mai University. The near 10-m-long facility consists of a radio-frequency (RF) electron gun, an alpha magnet, a 20-MeV linac, 9 quadrupole magnets, 3 transition and parametric X-ray radiation experimental stations, and a dipole magnet, etc. The system is featured for bunch generation and compression [5] with using a specially designed radiofrequency (RF) gun [6]. RF guns have been widely used in many applications due to their high accelerating field in the order of MV/m and high quality output beams. Rapid acceleration of electrons in the RF cavity results in the appreciable reduction of emittance growth from the space charge forces [7]. The RF-guns also have an advantage over conventional electrostatic DC guns owing to their production of relativistic electron bunches of higher current without needs of additional extensive buncher system. This leads to a compact and economical structure to produce high brightness electron beams with MeV kinetic energies. Due to being simple, compact, and economical, thermionic RF-guns are normally used as electron injectors for infrared free-electron lasers (IR FELs) [8 - 11], coherent THz sources [12 - 14], and synchrotron radiation facilities [15, 16]. For having femtosecond (fs) electron pulses, the RF-gun and a special magnet to compress the electron pulse from the RF-gun by a factor of about 1000 to obtain 100 fs electron pulses or shorter. The facility uses two microwave power sources. In the RF gun, electrons are continuously emitted with thermal energies from a thermionic cathode and are extracted and accelerated during an accelerating phase of the RF field with a frequency of 2856 MHz. At first, electrons are accelerated rapidly and reach the end of the half-cell just before the RF phase decelerates. They are further accelerated through the full-cell to reach the maximum kinetic energy of 2.0 –2.5 MeV at the gun exit depending on the accelerating field gradients. Later on, the electrons feel some decelerating fields and gain less and less overall energy, resulting in a well-defined correlation between energy and time. Electron bunches of 20 – 30 ps from the RF gun are then compressed in an alpha-magnet, where the particle path length increases with energy. This allows the lower energy particles, emitted later in each bunch, to catch up with the front for effective bunch compression. The optimized and compressed part of the electron bunch is then filtered by using energy slits located in the alpha-magnet vacuum chamber and is then transported through a SLAC (Stanford Linear Accelerator Center) type linac and a beam transport line to experimental stations. At the experimental stations, the bunches are compressed to less than 1 ps [17]. The operating and beam parameters are shown in Table 1. In formatting your A4-size paper (210 × 297 mm) with the text area 225 × 160 mm, set the margins as given in Table 1.

**Table 1**

*Operating and beam parameters of the SURIYA electron beam accelerator at CMU.*

| Parameters | RF-gun | Linac |
|---|---|---|
| Beam energy (MeV) | 2.2 – 3 | 6 – 10 |
| Macropulse peak current (mA) | 1000 | 50 – 150 |
| RF-pulse length (FWHM) (μs) | 2.8 | 8 |
| Repetition rate (Hz) | 10 | 10 |
| Beam-pulse length (μs) | ~2 | ~0.8 |
| Number of microbunches/macropulse | 5700 | 2300 |
| Number of electrons/microbunches | $1.4 \times 10^9$ | $8 \times 10^7$ – $6 \times 10^8$ |

**Terahertz (THz) Imaging**

The femtosecond electron bunches are used to generate intense THz or far-infrared radiation in the form of coherent radiation. Such radiation is of great interest for THz spectroscopy and THz imaging applications [18, 19]. After acceleration, the compressed electron bunches are used to generated coherent transition radiation (TR) by passing through a thin aluminum (Al) foil. The Al foil or radiator is tilted by 45º facing the electron beam direction. The backward transition radiation is emitted perpendicularly to the beam axis and is transmitted through a high-density polyethylene (HDPE). The radiation energy of 19 μJ per macropulse or a peak power of 24 W was measured by collecting over an acceptance angle of 160 mrad. The available THz radiation, measured using a Michelson interferometer with a room-temperature pyroelectric detector, covers wavenumbers from 5 $cm^{-1}$ to around 80 $cm^{-1}$ (0.15 THz – 2.4 THz). THz spectroscopy can be done easily by measuring the power transmission or the power reflection of a sample which is scanned using an XY-translation stage via a Michelson interferometer and the Fourier transformation, as well as with dispersive Fourier transform spectroscopy (DFTS). THz spectroscopy experiments, especially those on highly absorbing substances, using coherent THz transition radiation sources and DFTS techniques, have been reported [20]. Reflection and transmission THz imaging experiments have been conducted as examples of THz radiation applications using our radiation source [21]. It is possible to extend the spectral range further by using shorter electron bunches. A recent example is the femtosecond-based THz imaging of hydration state in a proton exchange membrane (PEM) fuel cell [22]. Imbalanced water management in the PEM fuel cell significantly reduces the cell performance and durability. Visualization of water distribution and transport can provide greater comprehension toward optimization of the PEM fuel cell. The work investigated water flooding issues that occurred in flow channels on the cathode side of the PEM fuel cell. The sample cell was fabricated with addition of a transparent acrylic window allowing light access and observation of the process of flooding formation (in situ) via a CCD camera. We explored potential use of terahertz (THz) imaging, consisting of femtoelectron-based THz source and off-angle reflective-mode imaging, to identify water presence in the sample cell. The THz image was constructed from reflected radiation revealing absorptive area of water presence.

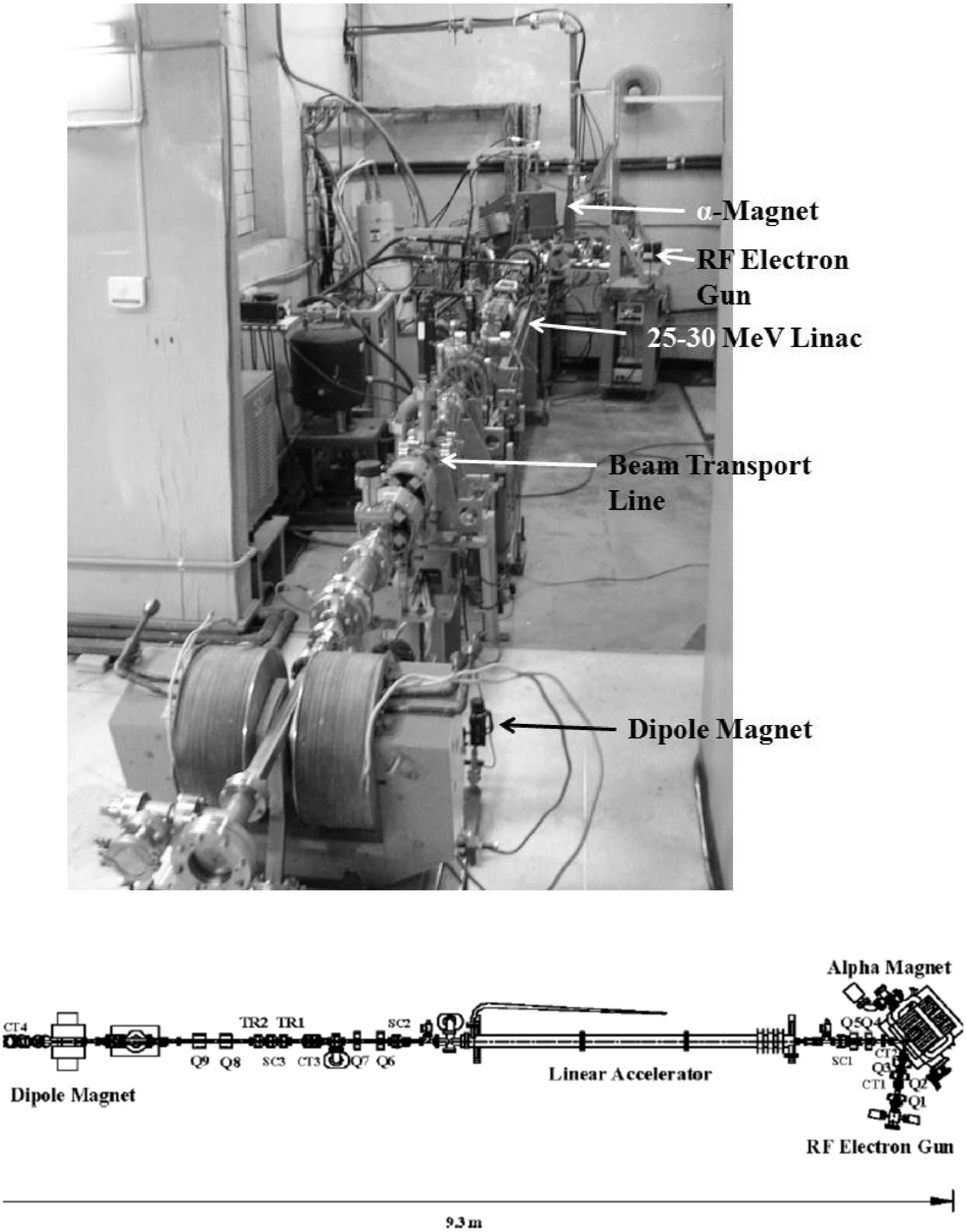


*Fig. 1. SURIYA facility. Upper: photo. Lower: schematic diagram of the layout of the SURIYA electron linac and beamline system at Chiang Mai University. Q: quadrupole magnet. CT: current monitor. SC: screen monitor. TR: transition X-radiation experimental station. PXR: parametric X-radiation experimental station.*

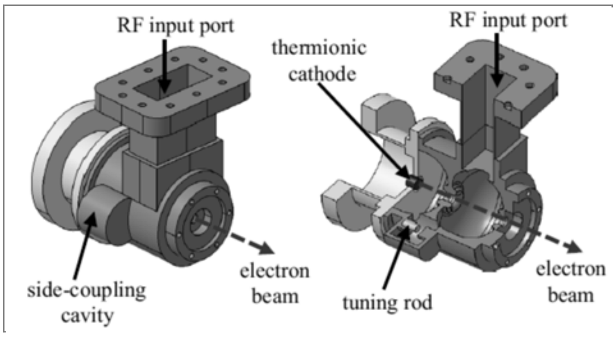


*Fig. 2. Schematic diagram in 3D and cut-view of the side-coupling thermionic RF gun of the SURIYA facility.*

A line-scan plot was utilized for quantitative analysis and for defining spatial resolution of the image. Implementing metal mesh filtering could improve spatial resolution of the THz imaging system. The THz imaging results were in agreement with simulations of two hydration states (water and non-water area).

### Recent Progress

The thermionic RF-gun for generating ultra-short electron bunches was recently optimized [23]. The RF-gun is a π/2-mode standing wave structure, which consists of two S-band accelerating cells and a side-coupling cavity. The 2856 MHz RF wave is supplied from an S-band klystron to the gun through the waveguide input-port at the cylindrical wall of the second cell. A fraction of the RF power is coupled from the second cell to the first one via a side-coupling cavity. Both the waveguide input-port and the side-coupling cavity lead to an asymmetric geometry of the gun. RF properties and electromagnetic field distributions inside the RF-gun were studied and numerically simulated by using computer codes SUPERFISH 7.19 and CST Microwave Studio 2012©. RF characterizations and tunings of the RF-gun were performed to ensure the reliability of the gun operation. The results from 3D simulations and measurements were compared. The influence of asymmetric field distributions inside the RF-gun on the electron beam properties was investigated via 3D beam dynamics simulations. A change in the coupling-plane of the side-coupling cavity was suggested to improve the gun performance.

A study on upgrading the SURIYA system to be an injector system for an infrared free-electron laser (IR FEL) is underway. The current system consists of an S-band thermionic cathode RF-gun, a bunch compressor in a form of alpha-magnet and a SLAC-type linear accelerating structure. Since characteristics of the emitted FEL light strongly depend on electron beam properties, a dedicated work to develop and optimize the injector system to drive the FEL is particularly important. Numerical study to optimize the longitudinal electron beam properties and some preliminary FEL simulations were conducted [24].

### Conclusions

The SURIYA electron beam program has been one of the emphatic objectives of the Thailand Center of Excellence in Physics to promote national high-level physics research for about 1.5 decades. Installed and developed in Chiang Mai University, the SURIYA facility is featured with the capability of production of femtosecond electron bunches in the energy order of 20 MeV realized from multiple electron beam compressions and acceleration from the RF electron gun, the alpha magnet, the linac, the beam transport line and the experimental endstations. The system has been developed for THz imaging applications and is being explored for infrared free-electron laser applications.

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