

DIAGNOSTICS OF FEMTOSECOND LOW-CHARGE ELECTRON BUNCHES AT REGAE*

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Abstract

A new linac is constructed at DESY as the electron source for “Relativistic Electron Gun for Atomic Exploration (REGAE)”. REGAE is mainly established for a Femtosecond electron diffraction experiment presenting structural information on atomic transition states occurring in the sub-hundred femtosecond time-scale [1]. REGAE comprises a photo-cathode gun followed by normal conducting 1.5 cell RF cavity to provide sub pico-Coulomb charge of 2 to 5 MeV energy with a coherent length in the range of 30nm. In order to produce and maintain such high quality electron bunches, sophisticated single-shot diagnostics is mandatory to monitor the properties. Diagnostics include emittance, energy, energy spread and bunch length measurement. In this paper the conceptual ideas and steps toward realization of these diagnostics are presented with a detailed focus on transverse diagnostics. As for photon source of transversal diagnostics, scintillators are studied. Simulation results show which material suits the best for REGAE parameters. Layout of a home-made intensified camera is presented. The method discussed in this paper would also be advantageous for low-charge Free Electron Lasers.

INTRODUCTION

An rf photoinjector is used to generate 2-5MeV relativistic short length electron pulses in REGAE. Structural dynamics in condensed matter on a femtosecond timescale within an Ultra Fast Electron Diffraction experiment [2] is going to be investigated. As it is well-known, space charge forces scale with γ^{-2} , therefore going to relativistic electrons improves the situation in terms of space-charge effects. Thereby, employing relativistic electrons in the beam plus decreasing number of electrons per bunch are two approaches to skip high broadening of the electron bunch during propagating from the cathode to the sample and improve temporal resolution. Created ultrashort electron pulses in the UED experiment, will make a possibility to resolve the dynamics of chemical reactions and phase transitions which usually occur on a 100fs time scale. While the sample thickness had to be on the order of 10 to 100 nm for lower energy electrons, REGAE can cope with thicker samples up to $1\mu\text{m}$. This capability opens up the door to more complex structures such as proteins in the crystalline and liquid phase.

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EXPERIMENTAL SETUP

REGAE is a pump-probe experiment in which temporal evolution of a sample is exerted by a short excitation pump laser and surveyed by a short electron probe pulse. According to ASTRA simulations [3] bunch length can be made as short as 7fs and coherence length as long as 30nm in the sample position. Small emittance of 6×10^{-3} mrad mm gives possibility of resolving complicated samples such as proteins. Pulse charge of 100fC makes it challenging to diagnose the beam profile in REGAE (see Table 1). Layout of REGAE accelerator is shown in Fig. 1. There are three diagnostics stations in REGAE setup. In the first diagnostic cross a scintillator crystal is installed for beam profile monitoring. The second cross contains a flat mirror mainly looking at the cathode and is employed to beam alignment purpose such as coupling the photocathode laser pulse. In the last station energy and energy spread of the beam is planned to be measured using a dispersive arm.

Table 1: Beam Parameters in REGAE

Electron beam energy	2–5 MeV
Beam charge	100 fC-1 pC
Bunch length	7–30 fs
Transverse emittance	6×10^{-3} mm mrad
repetition rate	50 Hz

The femtosecond pump and photo excitation pulse is provided by a commercial Ti:Sapphire laser. The third harmonic of the initial 800 nm laser is used to generate photo-electrons (see Fig. 2).

Scintillator Screen Monitor

The scintillator screen is mounted inside the beam pipe in 45° to the beam. Detector axis is perpendicular to the electron beam axis. Incident electrons on the screen excite the substrate and scintillation photons get released subsequently. The crystal material is Cerium doped Lutetium based scintillator, LYSO ($\text{Lu}_2\text{Y}_2\text{SiO}_5$) whose peak of scintillation emission occurs at 420nm. High light output, about 30 photons per keV deposited energy, and density of 7.1 g/cm^3 , make it a proper choice as the light source for low-charge electron beam diagnostics at REGAE. Furthermore, LYSO is in the category of fast scintillators with decay time of about 40ns, it means that major part of the produced light after excitation could be piled up in shorter time interval.

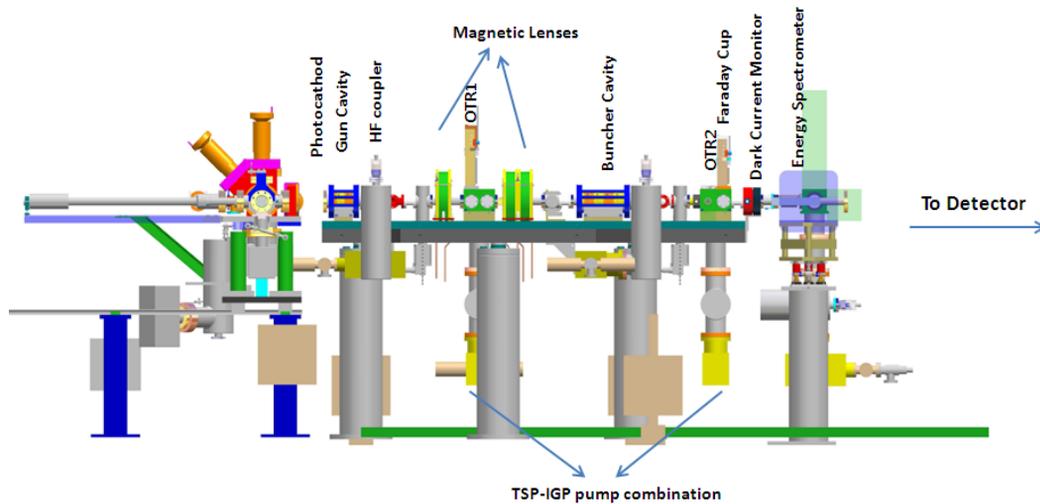


Figure 1: Layout of REGAE accelerator.

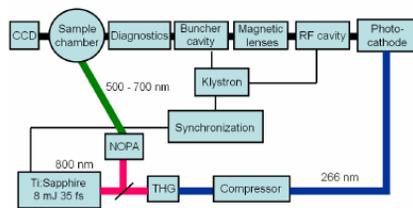


Figure 2: A simple layout of REGAE components.

Electron-Gamma Shower (EGS) [4] and Geometry and Tracking (GEANT) [5] are two Monte Carlo simulation packages to survey electron and photon transportation in specific geometry and material. Simulating electromagnetic interactions and luminescence phenomenon inside the crystal can be performed and cross checked to find optimum parameters for a particular experiment by both tools. In EGS one cannot go lower than 10keV, so generated events are just energetic electrons, x-rays and gamma rays. In GEANT4 scintillation photons can be detected; therefore with both tools we can cover a wide range of energy spectrum. In Fig. 3 a comparison for two different thickness of the same scintillator material is shown. At the top of the figure, two plots show the EGS simulation results for the 200 μ m and 500 μ m LYSO screens. Generated shower contains secondary electrons and photons. GAENT4 tool is used to simulate the output spectrum from a single electron incident upon different thickness of previous LYSO screen. The light yield is improved for thicker screen clearly but the drawback is the unwanted increase in the secondary electrons that ruins the resolution.

Image Detection

The produced light in scintillator should be transported and then imaged perfectly. For this purpose a proper op-

tics is required to collect the light efficiently and to form a fine image in detector position. The detector consists of an image intensifier coupled to a CCD. Whenever photons, inside upon the image intensifier, hit photocathode they will generate electrons which go through MCP and are multiplied by a significant factor, then the image is made on phosphor screen. The light after phosphor screen is not much collimated, in other words, intensifier tube behaves like a convex lens. Thereafter an achromatic lens focuses this image on CCD. While coupling the image intensifier to the CCD, there is flexibility to find proper enlargement of the image. Low charge electron bunches and consequently, low light intensity makes it essential to employ image intensifier; hence its performance in intensification needs to be tested and investigated. In a series of experiments detection efficiency of detection system was determined. The main idea was to start with an intense laser light and insert pairs of lenses to attenuate the light and end up with a faint intensity equivalent to several photons per each pixel on the CCD. Light intensity is tunable up to the point that we make sure any sort of signal is not detectable without the image intensifier. If switching to intensifier causes detection of an image in single shot it proves expected sensitivity of image intensifier in detecting low intensity. Then one can calculate how much intensity or in other words how many photons have exposed on each pixel which are just observable in presence of the image intensifier. Figure 4 shows an averaged frame over 20 shots but the signal is also detectable in single shot. While we have 24 \pm 2 photons per pixel nothing is resolvable without intensifier, then after mounting it, the image is visible, but as it was mentioned before, it causes an enlargement in the image size, therefore after the image intensifier, intensity level reaches to 8 \pm 2 photons per pixel. In this way, minimum detection threshold of the detector system is determined. In order to have an impression on the number of photons per pixel,

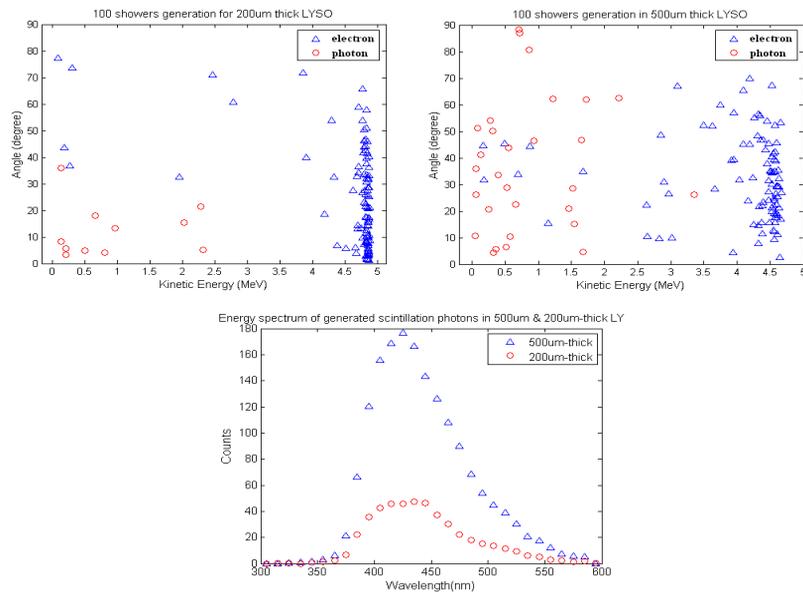


Figure 3: On the top, two figures show energy as a function of angle for produced secondary electrons and photons using EGS. In the bottom, Energy spectrum of generated scintillation photons on detector surface, located at the end side of each screen, are displayed using GEANT.

one can estimate that for instance if a beam with 1nJ energy illuminates the entire chip it is equivalent to almost 5000 photons per pixel.

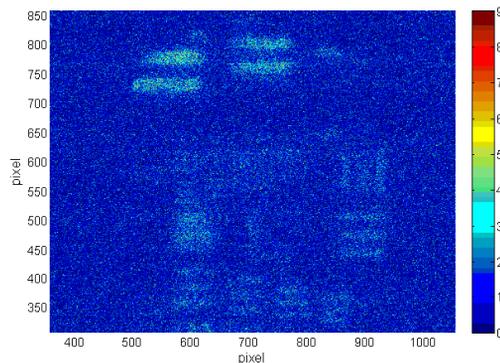


Figure 4: An intensified image of low intensity light on an AF target.

CONCLUDING REMARKS

Because of dealing with low intensity in diagnostics, higher light yield in scintillator is demanded but on the other hand it is desirable to keep spatial resolution which means required optimization in scintillator thickness and material. Beside that, collection efficiency of the optical setup, as well as light transport and detection efficiency have to be optimized.

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