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# AREAL low energy electron beam applications in life and materials sciences

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ABSTRACT

The AREAL laser-driven RF gun provides 2–5 MeV energy ultrashort electron pulses for experimental study in life and materials sciences. We report the first experimental results of the AREAL beam application in the study of molecular-genetic effects, silicon-dielectric structures, ferroelectric nanofilms, and single crystals for scintillators.



## 1. Introduction

The Advanced Research Electron Accelerator Laboratory (AREAL) is a laser-driven radio-frequency (RF) gun based linear accelerator project designed as a multipurpose facility in the fields of new accelerator technology and applied research [1,2]. The facility first stage, RF photogun, provides a 2–5 MeV energy electron beam with bunch charge of 10–250 pC. The usage of the AREAL electron beams in the fields of life and materials sciences is an important issue for exploiting the facility's full potential and its development. Although the advanced experimental techniques at the new facility, like relativistic electron diffraction [3], are under development, the experimental investigations in the fields of radiobiology, molecular physics, solid-state physics, and microelectronics are claimed. In this paper a short review of the AREAL performance and the first experimental results in life and materials sciences are presented.

## 2. AREAL facility and experimental set-ups

The basic aim of the AREAL facility is the generation and acceleration of ultrashort electron bunches with small transverse emittances. The main peculiarities of the AREAL facility are the relatively broad range of beam parameters variation and stable machine operation within this range. The design specification of the facility implies the usage of the metallic photocathode and an ultrafast UV laser. The choice of the metalic (copper) photocathode is stipulated by a high-damage threshold (100 mJ/cm$^2$), short response time ($<0.02$ ps) and a long lifetime ($\sim$1 year) that provide the facility reliable operation with sub-picosecond electron pulses at the gun exit. The RF gun is driven by the Yb doped laser system capable to provide about 200 μJ energy at 258 nm wavelength and 0.4–9 ps pulse duration. The main parameters of the AREAL laser system and electron beam are presented in Tables 1 and 2, respectively.

The diagnostic tools include the magnetic spectrometer, Faraday cups, YAG screens, and pepper port for the beam energy, energy spread, charge, beam profile, emittance measurements, and control.

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The facility schematic layout is presented in Fig. 1. The machine set-up provides a good basis for the facility development and the start-up of the first experiments. The facility has two in-air experimental stations H1 and H2 for applied research in the fields of life and materials sciences. The first station H1 with a focused electron beam is located downstream of the linac. The second station H2 is designated for the electron energy correlated experiments and is located after the magnetic spectrometer in order to avoid the dark current effects. The beam profiles at the experimental stations H1 and H2 are presented in Fig. 2. The experimental stations are separated from the accelerator vacuum chamber (~1 nTorr vacuum) by special Titanium windows.

## 3. Bio-medical applications

Innovative experimental in vitro investigations in radiobiology are of crucial importance for understanding the basic mechanisms of radiation damage of the cell [4–7]. The 2–5 MeV energy AREAL ultrashort electron bunches are a very appropriate tool for precise and controllable studies in radiation biology and medical physics in a wide range of applied radiation doses.

**Table 1**
UV laser parameters.

| | |
|---|---|
| Wavelength (nm) | 258 |
| Pulse energy (μJ) | 200 |
| Repetition rate (Hz) | 1–100 |
| Energy stability | < 2% |
| Beam divergence (mrad) | < 0.3 |
| Beam diameter (mm) | 4.0 |

**Table 2**
AREAL beam parameters.

| | |
|---|---|
| Energy (MeV) | 2–5 |
| Bunch charge (pC) | 10–250 |
| Bunch length (ps) | 0.4–9 |
| Norm. emittance (mm-mrad) | < 0.5 |
| RMS energy spread | < 1.5% |
| Repetition rate | 1–50 Hz |

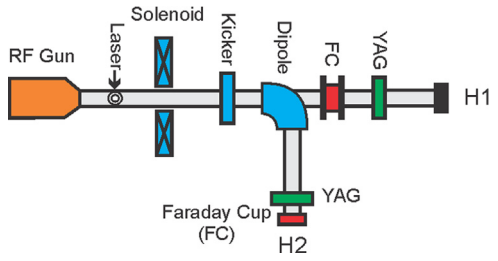


**Fig. 1.** AREAL RF photogun layout with experimental stations H1 and H2.

### 3.1. Genetic effects. DNA radiation damage and repair

The dose–response effects of reparable and non-reparable DNA damages induced by the AREAL electron beams have been studied. The first step toward the application of electron beams in radiobiology is the development of biodosimetry based on molecular-genetic effects of radiation on DNA as a principal biological target for the radiation damaging action.

To estimate the level of primary DNA damage, as well as the repairable and non-repairable DNA damages, after cell irradiation the comet assay (single cell gel electrophoresis) was carried out under alkaline conditions [8]. The study of irradiation-induced primary DNA damage was performed by comet assay of the cells which after irradiation were kept for 3 h under dark and cold conditions to prevent DNA repair. Repairable and non-repairable DNA damages were assessed after 24 h-incubation of irradiated cell culture in complete growth medium at 37 °C. The level of DNA damage was defined by the tail moment given as the relative amount of DNA in the tail of the comet multiplied by the median migration distance.

The exposure of K562 human chronic myelogenic leukemia cells to ultrafast electron irradiation at different doses revealed the dose-dependent increase of the primary DNA damage. Fig. 3 represents the comets images (qualitative data of primary DNA damage) 3 h after irradiation. Non-irradiated cells appeared as spherical nucleoids with no DNA migration (Fig. 3a). All cells were examined and captured using a fluorescent microscope at 400 × magnification. The low dose of irradiation (2 Gy) leads to the formation of few strand breaks (Fig. 3b), while doses of 4 Gy, 8 Gy and 16 Gy generate significant increase of strand breaks as compared to control. These cells have a long tail of DNA streaming out of the nucleoid and form a comet-like appearance (Fig. 3c–f). A significant increase in DNA strand breaks 3 h after the irradiation was observed at all doses applied (Fig. 4). Meanwhile, the decrease of DNA damage level at doses higher than 4 Gy is revealed. This observation may be due to the loss of highly damaged non-viable cells from the population, which results in a lower level of DNA damage in the remaining viable cells. After 24 h of cell incubation, the damaged DNAs have repaired up to irradiation dose of 24 Gy (Fig. 4). The increased level of DNA damage after 24 h of incubation at 24 Gy irradiation dose can indicate the increase of viable cells population with a higher level of damage.

It is known that there are qualitative differences between the low and high linear energy transfer (LET) radiation both in

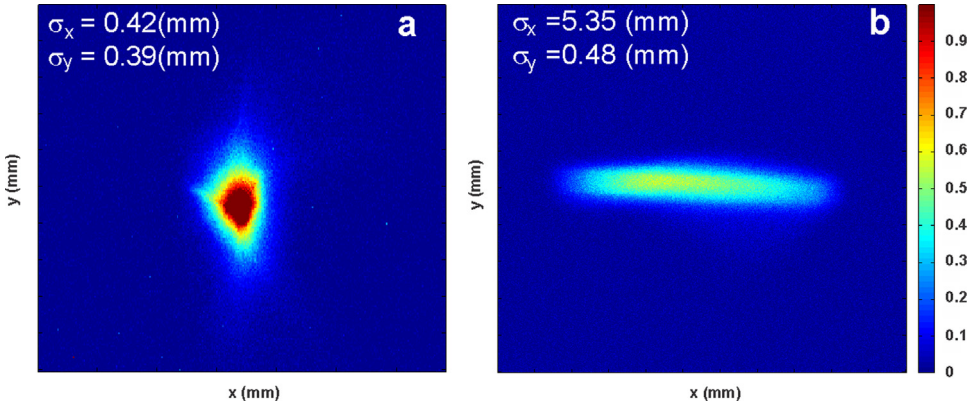


**Fig. 2.** Electron beam transverse profiles at experimental stations H1 (a) and H2 (b).