doi:10.1017/S1431927611008063
Microsc. Microanal. 17 (Suppl 2), 2011

Design Concept for 100kV-Level, 1.5-cell, RF Photo-Guns

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Ultrafast electron microscopy (UEM) aims to combine the high spatial (sub-nm) resolution of electron microscopy with the high temporal (sub-ps) resolution afforded by today's ultrashort pulse lasers [1]. In order to attain the desired high time resolution at the specimen, temporal electron pulse broadening due to both the intrinsic dispersion (i.e., a finite non-zero energy width) and intra-pulse space charge effects must be reversed. For the necessary electron pulse compression, the use of a RF cavity after a 100kV-level DC photo-gun has been proposed [2], and recently demonstrated [3], for ultrafast electron diffraction (UED) experiments. A potential alternative to such two component systems is a RF photo-gun in which electron acceleration and pulse compression can be combined in a single device. However, RF photo-guns generally operate at relativistic (a few MeV) electron energies, where electron optics for microscopy have not been developed and the small electron wavelength thus implies large post-specimen distances for UED measurements [4,5].

Here we present a design concept for a 100kV-level RF photo-gun suitable for both UED and UEM applications. The RF gun borrows the same basic 1.5-cell geometry of MeV-level relativistic photo-guns [4,5], but the cell length and RF field amplitude are reduced to allow for operation at ~100kV. Figure 1 shows the performance characteristics of a 1.3GHz (L-band) 100kV RF gun with a 34mm cell length. A contour plot of the exiting electron energy as a function of the RF phase (ϕ_{RF}) at photoelectron generation and the RF field amplitude (Figure 1(a)) indicates that this gun geometry is capable of operation in the range ~90-150kV. Reduction of the cell length allows for lower energy operation (e.g., a 25mm cell length for ~50kV), while longer cell lengths provide higher (relativistic) electron energies. Analysis of the RF field supported by the 100kV gun using SUPERFISH produces the characteristic sinusoidal axial field amplitude of a 1.5-cell RF gun (Figure 1(b)). Figure 1(c) shows the performance of the 100kV RF photo-gun for a RF field amplitude of 3.1MV/m and $\phi_{RF} = 0.27\pi$ (49°) – conditions under which a temporal focus (minimum longitudinal length) of the electron pulse is generated at a distance of 30cm after the gun. The latter simulation of the electron pulse propagation dynamics, using an extended analytical Gaussian (AG) model [6], also indicates that the minimum duration of the compressed electron pulse can be more than 100 times less than the duration of the laser pulse incident on the gun's photocathode [7,8]. Simulations of the RF gun performance using PARMELA (a particle tracking (GPT-like) code) are consistent with results obtained using the less computationally intensive AG model.

The effect of intra-pulse space-charge on the temporal pulse compression fidelity and the required RF drive power levels to operate the RF photo-gun will be discussed. The performance and relative merits of the 1.5-cell RF photo-gun will also be compared to two other compact 100kV-level photo-gun technologies capable of providing temporal pulse compression: (i) the single-cell 'pill-box' RF photo-gun proposed by E. Fill *et al*. [7], and (ii) the hybrid DC-AC photo-gun (i.e., a RF pulse compression cavity directly after a DC photo-gun) analyzed by L. Veisz, *et al*. [8].

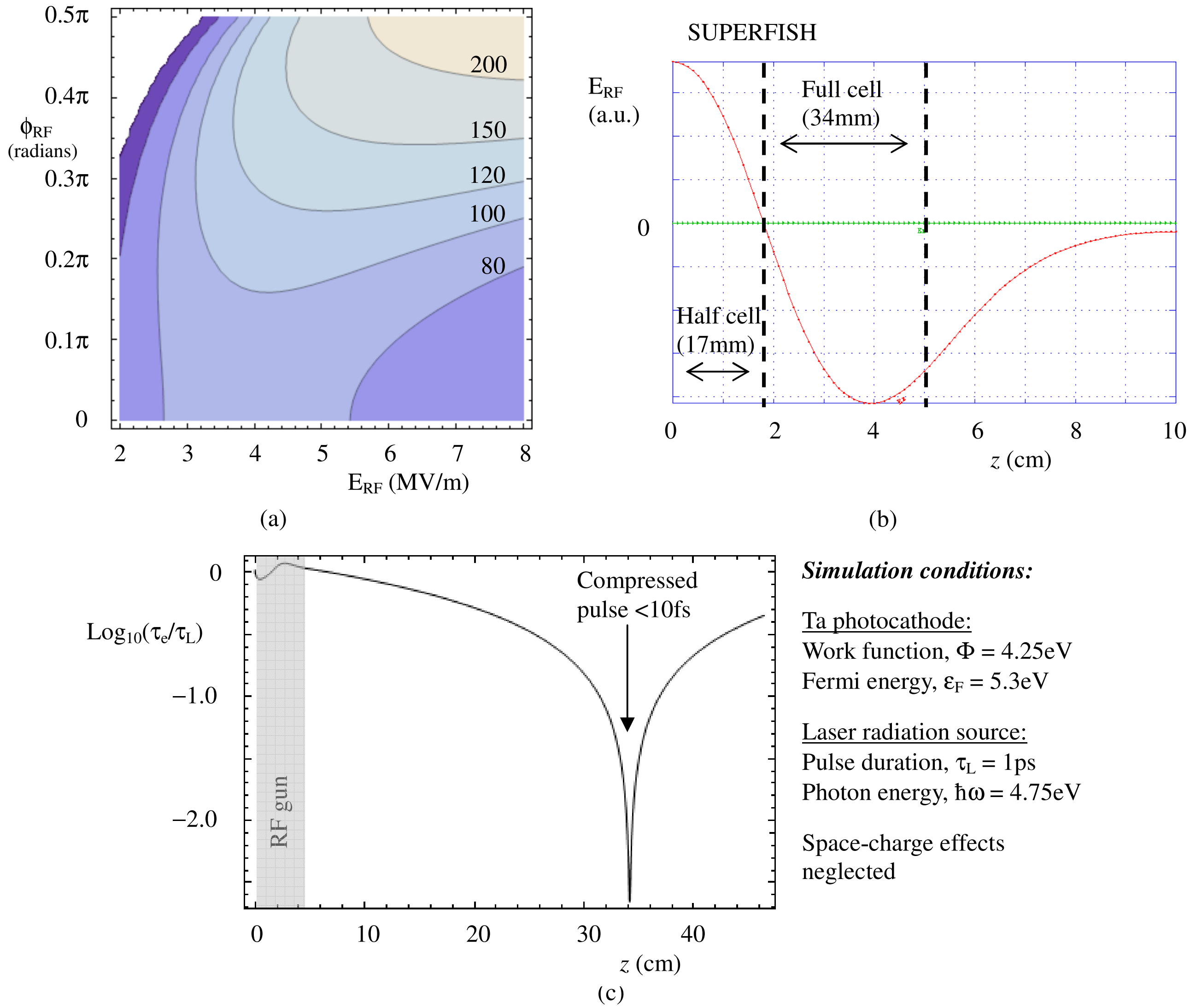

FIG 1. (a) Contour plot of the exiting electron energy (labeled in kV) as a function of the RF phase (ϕ_{RF}) at photoelectron generation and the RF field amplitude. (b) SUPERFISH evaluation of the axial RF field amplitude in the 1.5-cell photo-gun with a cell length of 34mm. (c) Ratio of the electron pulse duration (τ_e) to the laser pulse duration (τ_L) for $E_{RF} = 3.1$MV/m and $\phi_{RF} = 0.27\pi$.

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[9] This research is supported by the Department of Energy (DE-FG52-09NA29415) and the National Science Foundation (DMR-0619573). J.A. Berger acknowledges the support of a Department of Education GAANN Fellowship.