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SUMMARY OF WORKING GROUP 3A: LOW EMITTANCE SOURCES*

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Abstract

We summarize the main issues and conclusions of the working group devoted to low emittance sources.

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INJECTOR OVERVIEWS, PHOTOCATHODE DRIVE LASER, MODELING

Overview of Photo Injectors

Experimental and design data for 15 different photo injector projects that includes DC and NC and SC RF photo cathode guns producing from 1 pC to 10 nC bunches with time structure from single bunches at 10 Hz to cw beams and emittances ranging from 0.1 to 11 mm-mrad are summarized.[1] Simulations predict very good performance by all three basic photo injector types (plus hybrids). Experimental progress has been made for each of the major subsystems—gun, laser, diagnostics—and on measured beam quality, although the challenge to "Get 1 μm @ 1 nC" announced by P. O'Shea at the 1999 ICFA workshop at UCLA has not yet been reached. Methods to reach this goal are defined.

Besides the known methods to produce low emittance beams from the three basic photo injectors, new ideas include the generation of bunches that at the cathode have either a pancake shape with a half-sphere transverse profile or a cigar shape with a parabolic longitudinal profile. These are shapes that can evolve into an ellipsoidal distribution in space which results in linear space charge forces and low emittance. A second new idea is to generate the bunch not from a conventional cathode at all, but from cold atoms trapped in an inhomogeneous B field.

In the future, as progress is made toward emittances that approach the limit set by the thermal emittance, it will become increasingly important to understand better the emission process itself.

UV Pulse Shaping

To achieve a low emittance, a flat or top hat pulse shape, spatially and temporally, is desired. Spatial shaping of uv pulses directly using a deformable mirror (DM) is compared with a micro lens array (MLA).[2] DM is superior with respect to wave length limit, achievement of ideal profile and pointing adjustability, but at present is significantly more expensive. With an electron profile monitor and a feedback algorithm both methods can be used to correct for inhomogenities in the distribution of QE on the cathode surface.

Temporal shaping of uv pulses can be performed with a spatial light monitor (SLM). Two types are discussed. An acousto-optic SLM such as the Dazzler is able to modify spectral phase and amplitude. It is generally more versatile than a fused-silica SLM although it is more expensive.

Finally, ellipsoidal shapes can be produced by simultaneous use of DM plus an optical fibre bundle. However, this technique is limited to cathodes that can be illuminated from their back surface.

Multiscale Methodology

A wavelet-based solver for the 3D-Poisson equation was developed to account for multi-scale dynamics in multi-particle simulation codes.[3] It initially was included in an N-body PIC code and tested with an IMPACT-T simulation to reconstruct in detail the charge distribution of a 1-nC bunch from the FermiLab NICADD photo injector both before and after compression. Initial results show a 15-20% increase in speed while the number of data sets is reduced by 1/10.

PHOTOCATHODE MATERIALS, POLARIZED ELECTRONS, THERMAL EMITTANCE

Thermal Emittance of Cs_2Te

As the techniques for producing lower emittance sources continue to progress, the limit set by the thermal emittance, ε_{th}, becomes more important. Recently ε_{th} for Cs_2Te cathodes was measured for the first time in the operating conditions of an RF gun using the scanning slit method.[4] For this experiment, ASTRA simulations were used to confirm that space charge and RF contributions to the total emittance from the 3 pC, 3 ps bunch produced by the 1.6-cell RF L-band gun would be a small perturbation. ε_{th} is derived from the slope of the measured emittance as a function of laser rms spot size, σ, at the cathode. The result averaged over x and y for two cathodes is a normalized rms emittance of ε_{th} = 1.1 mm-mrad per mm σ, corresponding to an average kinetic energy of ~1 eV at the cathode surface..

Polarized Photocathodes

To generate highly polarized beams, many types of photocathodes based on GaAs have been tried, including single strained-layer GaAs and both unstrained and strained superlattice structures. The best choice today is the strained GaAs-GaAsP superlattice, which yields an electron polarization of 90% with a QE of 0.5% using laser excitation of visible wavelength.[5] A second critical factor for polarized sources is dark current, which must be maintained below an average of ~10 nA. Extensive testing of electrode materials for DC guns has led to the finding that the best choice is Mo for the cathode, Ti for the anode. With proper cleaning, this combination results in only 1 nA average peak current at 130 MV/m after high-voltage processing.

Polarized RF Gun

GaAs photocathodes have not yet been successfully used in RF guns. The principal problems are recognized to be back bombardment of the cathode by field-emitted electrons and the required vacuum of better than 10^{-11} Torr.[6] It should be possible to significantly reduce field emission. A single S-band cavity carefully manufactured and cleaned has been processed to a peak surface field of 140 MV/m with a peak current of <25 pA, which for the ILC duty factor corresponds to an average current of <1 pA! The vacuum of a NC RF gun can be improved by surrounding the gun in a UHV system and then pumping through Z slots or multiple small holes (a sieve) in the outer cylinder. Further improvement in the conductance between the cathode and the pumping system is possible using RF gun designs that have a more open structure, such as PWT or HOM designs. The latter, combined with a sieve, results in at least a factor 20 improvement in the conductance compared with conventional RF gun vacuum systems. This results in an expected pressure at the cathode of $<10^{-11}$ Torr after RF processing if the outgassing rate is reduced to that of well-baked Cu.

LOW EMITTANCE ELECTRON GUNS

SC RF Guns

The status of SC RF guns is reviewed.[7] The guns being developed range from hybrids in which the cathode is NC, to all-Nb SC cavities. Cathode materials that are being studied include Cs_2Te, Pb and CsKSb/diamond as well as Nb. Emittance compensation for SC RF guns is a problem. An interesting emittance-compensation possibility for a multi-cell gun is to operate one of the cells in a magnetically focusing RF mode.

Ultra-Low Emittance,Ultra-Short Bunch Length

RF guns are routinely selected as the electron source for low emittance beams. A 1.6-cell S-band RF gun with a Cu cathode has been used to generate an ultra-low emittance bunch.[8] With a flat top laser pulse of 9 ps and a charge of 1 nC, an emittance of 1.2 mm-mrad was measured. When running at a reduced charge of 0.17 nC and after passing through a phase-optimized accelerating section, a pulse length of 98 fs was obtained.

Thermionic RF Gun With Independently Tunable Cells

A thermionic RF gun is described that has independently tunable cells.[9] By tuning the cells for velocity bunching, external bunching stages can be eliminated, resulting in a very simple configuration. This type of gun is being developed for a coherent THz SR source, but should be of interest for any application requiring high current.

DC thermionic gun for SCSS

To avoid the dark currents associated with an RF gun and also the non-linear space charge field associated with pulsed charge extraction, a pulsed thermionic gun is being developed for SCSS in which a 2-ns pulse is selected downstream from the 1 μs pulse produced by a 500 kV gun.[10] The normalized emittance at the cathode is measured to be 1.1 mm-mrad. The CeB_6 cathode using a graphite heater can produce current densities >40 A/cm^2. The theoretical thermal emittance for this cathode is 0.4 mm-mrad.

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