Sub-nanosecond electrical gating for metal field emitter arrays

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***Abstract*—Field Emitter Arrays (FEA) are an attractive candidate to replace thermionic and photo-cathodes as a source of a high quality electron beam, reducing cathode power consumption and increasing reliability. For some applications (accelerators, microwave amplifiers) it is necessary to modulate or produce electron pulses with sub-nanosecond time structure. Sine wave grid modulation of an FEA cathode up to few GHz has already been demonstrated [1, 2]. Sub-microsecond pulsed electron emission was also reported by S. Leemann et al. [3]. Our interest was to explore the limitations of short electron pulses generation based on electrically gated FEAs. Since field emission is an instantaneous process the main modulation speed limitation is due to the finite FEA gate capacitance. Using short current pulses to control the gate potential we demonstrated that FEAs are capable of generating single sub-nanosecond electron pulses. The practical implementation of the method and its limitations are discussed.**

Keywords—Field emitter arrays, short electron pulses, field emission, electrically operated FEAs

I. INTRODUCTION

The discovery that Diamond-Like Coated (DLC) electrodes can withstand electric gradients of few hundreds MV/m without conditioning [4] was an important step towards introducing FEAs in high gradient environments. With a DLC coated cathode protecting the edges of the FEA chip it was demonstrated that FEAs could operate at gradients up to 30 MV/m emitting 4 ns long (FWHM) pulses with peak current of 200 uA [4, 5]. The speed was basically limited by the self-resonance of the gate capacitance and driver inductance. Since we were conducting these experiments in an accelerator cathode gun, it was useful to shorten the emitted electron pulse down to fraction of the period of the RF accelerator cavities.

II. DOUBLE PULSE CURRENT INJECTION METHOD

Numerical electromagnetic simulations of the FEA geometry showed that transit time across 2 mm diameter gate is <20 ps so the FEAs should be able to produce pulses at least down to few 10s of ps [6]. Developing the "double pulse" current injection method made possible to overcome the self-resonance frequency limitations and to modulate the gate potential in sub-nanosecond time scale. Two short (< 1 ns) opposite polarity high voltage (HV) pulses of up to 3kV, delayed about 1 ns, inject and remove charge quickly in the FEA gate capacitance. The high voltage overcomes the parasitic inductance of the electrical connections. Since the gate voltage is proportional to the injected charge, the gate is not damaged by the incoming HV pulses unless too much charge is injected, raising the gate voltage above the breakdown limit of the FEA gate. *Fig.1* shows the two basic schemes that were used to generate two opposite polarity voltage pulses from the initial single polarity HV pulse: *a)* with shorted transmission line (reflected pulse with opposite polarity) and *b)* with pulse differentiation [8].

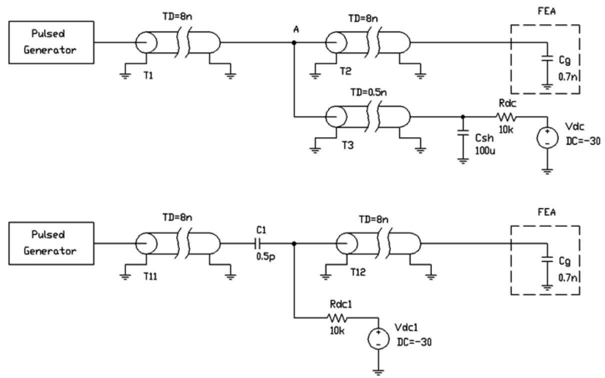

Fig. 1. Two basic schemes for generating opposite polarity HV pulses: *a)* with shorted transmission line and *b)* with pulse differentiation.

A static bias voltage was added so that the amplitude and width of the FEA gating pulse could be reduced.

III. EXPERIMENTS

The first experiments were done in low gradient (up to 0.4 MV/m) and lower accelerating voltage (up to 4 kV) test stand. The results in Fig. 2 show that, for the same gate conditions, there was a clear tendency to get shorter pulses with higher accelerating voltage [8, 9]. The pulse width reduced to 525 ps at an accelerating voltage of 4 kV [9]. Extrapolation of these results implied that the emitted pulses were even shorter (~400 ps [8]) but that they tend to smear due to intra-pulse space charge forces. The expected pulse duration value was shorter than the period of an available RF accelerating structures operating at 1.5 GHz and so it became possible to study FEA generated electron pulses accelerated to relativistic energies (≤ 5 MeV). High cathode gradients and voltages are useful to limit space charge expansion of the electron bunch.

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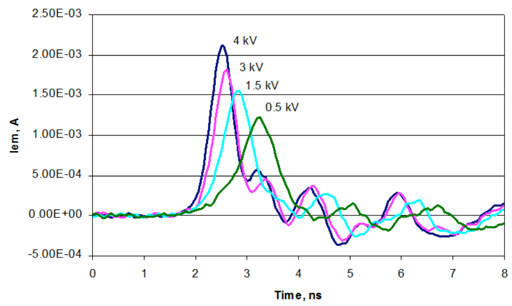

Fig. 2. A family of electron pulses emitted by an electrically driven FEA with same gate conditions and different accelerating voltage.

An FEA holder and the "double pulse" gating connections were integrated into the accelerator cathode. Using an RF phase scan between the emission time and RF accelerator phase 30.5% charge modulation was observed confirming emitted pulses are around 400 ps long [7, 9]. As best we know, this was the first demonstration of electrically gated FEA being used as an accelerator cathode source in single pulse mode. Unfortunately, not long after these experiments the test accelerator was decommissioned. Only in another medium gradient test stand were further studies possible. From this test stand, *Fig. 3.* shows the shortest recorded electrically gated FEA pulse (210 ps [6]). This result was obtained with 40 kV accelerating voltage and electric gradient > 3 MV/m. The "differentiation" scheme was used to produce the HV pulses necessary to control the gate potential. The electron bunch is recorded using broad bandwidth coaxial Faraday cup and a LeCroy WavePro 7300A, 20 Gs/s oscilloscope.

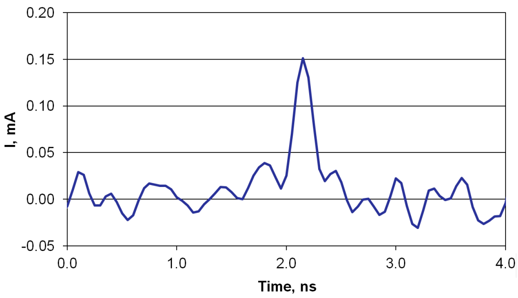

Fig. 3. Shortest recorded electron pulse (210 ps FWHM) with 40 kV accelerating voltage.

IV. Conclusion

A series of experiments showed that FEAs can operate in high gradient environments (up to 30 MV/m) by mounting the FEA chips in a DLC coated holder. Using the developed "double pulse" current injection method, the self-resonance frequency limitation can be overcome and the FEA gate voltage can be changed rapidly. Using the "double pulse" method, sub-nanosecond pulsed electron emission from electrically gated FEAs was demonstrated.

Acknowledgments

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