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RECENT DEVELOPMENTS OF GIGATRON TECHNOLOGY

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Abstract Gigatron is a new design concept for microwave power devices. A gated field-emitter array is employed as a directly modulated cathode. A ribbon beam configuration is used to mitigate space-charge effects and provide for efficient output coupling. A traveling-wave output coupler is used to obtain optimum coupling to a wide beam.
Recent cathode tests are reported. Modeling of the bunched-emission process has led to an improved cathode fabrication procedure. A new application of a similar structure has led to a design for a new technology for precision tracking chambers for SSC detectors.

INTRODUCTION

The Accelerator Research Laboratory at Texas A&M University is developing a new technology, called gigatron[1], which appears to offer great promise for compact microwave power sources. In the gigatron, a fully modulated electron beam is produced from a gated field-emitter array (FEA) cathode. The bunched beam is then accelerated through a high-voltage diode structure into a resonant output coupler. Several significant innovations have been introduced to achieve high-efficiency, high frequency, and high power in a compact device.

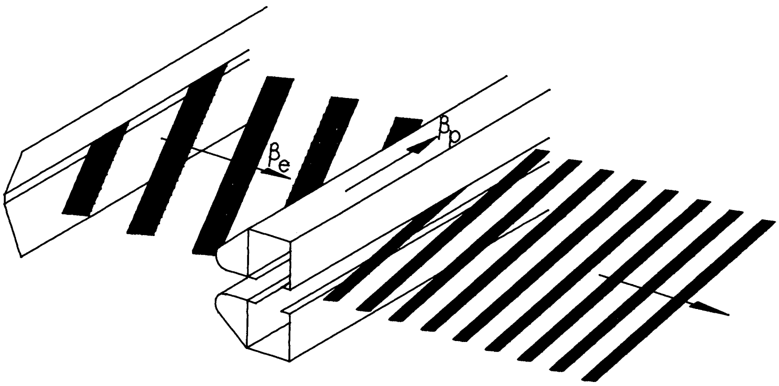
Two configurations of the gigatron are envisioned, for medium and high power applications. For medium power applications, a round electron beam is passed through a cylindrical standing-wave coupler in the traditional way. The modulated beam can instead be extracted for further acceleration, serving as a compact particle source for high-frequency linacs. For high power applications, a ribbon beam is employed. The output coupler consists of a section of slotted rectangular waveguide, configured to permit the passage of the ribbon beam parallel to the electric field of a traveling wave. By a suitable matching condition, each component of the ribbon beam encounters the same rf phase: the beam "surfs" on the traveling wave, as shown in Figure 1.

The choice of round beam or ribbon beam is governed by the output power required for a given application. One example of a round-beam application is the design shown in Figure 2. It is a tiny 12 GHz cathode, rated for 100 A/cm^2 peak current density and 50 kV diode voltage. The cathode structure forms a matched termination to a 50 Ω coaxial line as shown.

One example of a ribbon beam application is shown in Figure 3. It is a 1 m long ribbon gigatron, designed to produce 70 MW peak power at 18 GHz. Eight such gigatrons can be configured in a compact cylindrical array, to produce 500 MW pulse power with high efficiency. Because the device has extremely large collector surface area, it can also support a much larger average power than any known alternative. A continuous string of these devices could be used to provide ~1 m periodic drives to a TeV linac collider.

THE GIGATRON DESIGN CONCEPT

Current technology for millimeter-wave sources is severely limited in power and efficiency for frequencies beyond ~10 GHz.



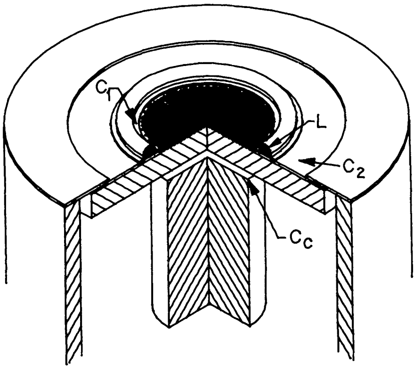
1. Ribbon electron beam and traveling wave coupler.

Almost all current devices (TWT, klystron, FEL, gyroklystron) employ the same basic *e*-beam strategy:

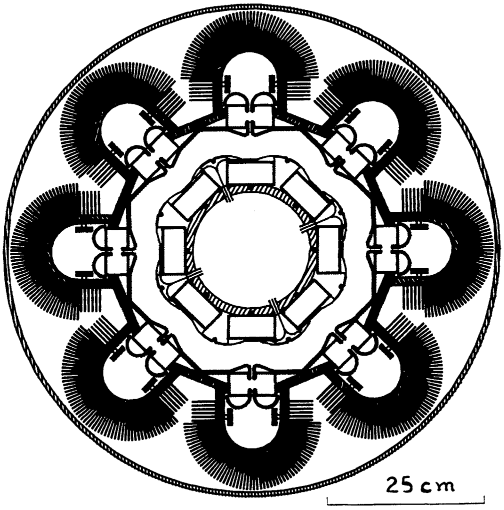
- a dc electron beam is accelerated through a high-voltage diode;
- the beam is modulated (in energy or direction) by an input cavity;
- the beam transverses a drift region in which the above modulation produces a phase modulation of the beam current;
- the rf current passes through an output cavity where the beam is decelerated and the rf power is coupled to a waveguide.

The main limitations to high-frequency performance arise in the bunching process. The electric potential within an electron beam is depressed by the space charge of the beam itself. When voltage modulation is applied to the beam in the input buncher, the resulting energy modulation is smeared by the spread in space charge potential, and ultimately limits the bunching process. The buncher also produces transverse fields which perturb the transverse motion of the beam, and require focussing magnetic fields to confine transverse growth.

The proposed source removes the requirements of buncher and



2. FEA cathode and resonant coupler for coax mount.



3. Gigawatt Ribbon Gigatron

drift region, thereby cutting the Gordian knot of tube design. The beam is produced from a gated field-emitter cathode; the beam is fully modulated from birth. It is accelerated across a high-voltage diode and then enters an output coupler where the beam is decelerated against the coupler field to drive output power. There is no bunching cavity and no significant drift region. The tube design approaches an impulse approximation, in which the beam has minimum time to respond to perturbing forces. The result is high efficiency of rf conversion, high power capability, compact structure, no requirement of magnetic guide fields, and suppression of parasitic modes.

1. Gated field-emitter cathode studies.

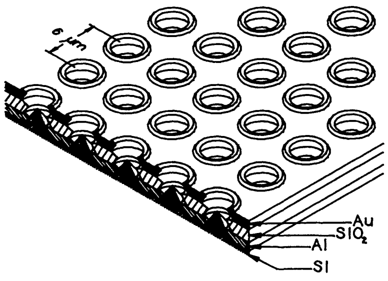
The gated field-emitter (FEA) cathode appears to offer an attractiv new technology for achieving a high current, fully modulated electron beam directly from a cathode structure. C.S. Spindt *et al.*[3]and H. Gray *et al.*[4] have developed microfabrication techniques by which they can prepare planar arrays of gated field-emitting points. Gray uses directional etching techniques to produce atomically sharp needle and knife-edge arrays directly on silicon. A silicon-insulator-metal gate structure is then deposited on the cathode substrate, and plasma-etched to form a planar array of micro triodes. Application of a modest (25 V rms) gate-cathode voltage results in full modulation of emission current. Stable, uniform emission of up to 1000 A/cm^2 has been achieved. There is no evidence ofin-service deterioration during extended life tests.

We have tested FEA cathodes at Texas A&M. The cathodes were made for us by C.S. Spindt, and employ his fabrication approach. DC-IV curves of these cathodes are presented in Figure 4. The Fowler-Nordheim IV dependence characteristic of field emission is observed. The saturation at high current is caused by the space charge limit of the gun used for cathode tests. We have built a vacuum assembly for testing the IV characteristics of cathodes in pulse mode, including provision for rf modulation. We have also built the complete vacuum structure for a round-beam gigatron prototype, with design parameters 12 GHz, 40 kW.

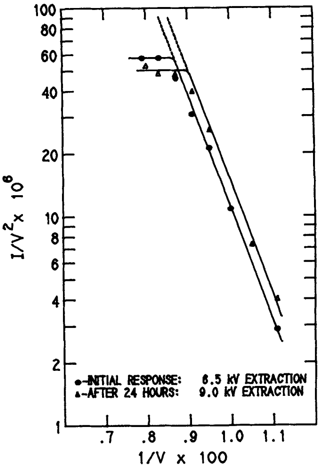
We have improved upon the fabrication procedure of Gray and Spindt in two respects that are critical to achieve high-frequency modulation. First, the silicon surface is metalized after formation of the field-emitting tips, as shown in Fig. 5. This provides a metal base surface for low-impedance charging of the FEA tips. In previous devices charging current must flow through the bulk of the silicon substrateresulting in an unacceptable charging resistance at high frequency.

Second, a fabrication process has been devised whereby an optimum field geometry can be produced for efficient gate modulation. The electric field between the tip and the gate iris controls the field emission process. A fabrication sequence has been devised by which the tip/iris spacing can be reduced to a fraction of a micron, while preserving ~3 μm path lengths at all insulator surfaces for gate voltage isolation. In this way the modulation voltage required to control current emission can be significantly reduced.

Third, the beam optics in the tip/gate region has been optimized to produce quiescent electron emission. The optics of the electron beam emission from the tip/gate region determines



4. Gated field-emitter array cathode.

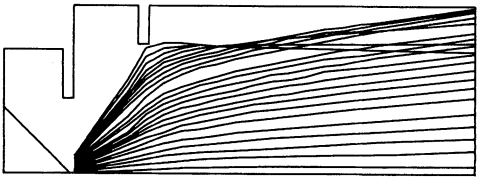


5. Experimental I/V response of FEA arrays.

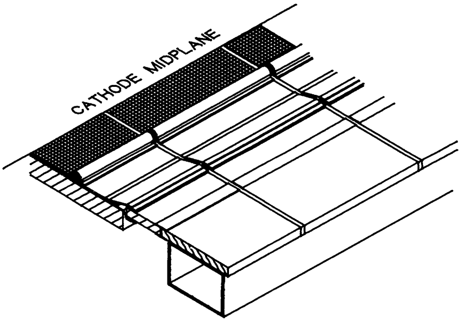
the initial emittance of the beam in the gigatron. We have calculated the beam dynamics during field emission using the computer code MASK[4]. Beam is assumed to be emitted from the tip into a cone of half-angle $\pi/4$. Figure 6 shows the transport after emission from a two-gate FEA structure. The tip-gate geometry of the cathode forms an approximate point-to-parallel lens. As a result the emitted beam has a much smaller emittance than the previous estimates based simply on assuming a transverse temperature $T \sim eV_m$. If in fact this improved emittance can be realized, the FEA cathode may also be an excellent candidate for electron sources for linacs, FEL's etc.

3. Resonant input coupler.

The field-emitter array presents a highly reactive load to a modulation driver. Matching can be optimized by configuring the cathode within a sequence of coupled lumped-constant resonant circuits, as shown in Figure 7. The gate/base junction of the FEA constitutes a capacitance C_1. A metalized quartz fiber is mounted adjacent to the FEA, and the metal-insulator-metal layers (without tips) are continued laterally to form a tuning capacitance C_2. The gate layer metalization and quartz fiber metalization are interrupted along the region where the fiber contracts the insulating layer, so that rf currents to/from the gate layer must flow around the fiber - it acts as an inductor L. The system C_1 - L - C_2 then forms a resonant circuit whose frequency can be controlled by choice of the radius of the inductive



6. Acceleration of an electron bunch from an FEA cathode.



7. FEA cathode and resonant coupler for ribbon beam.

fiber. The resulting localization of charging currents produces a minimum resistance and maximum Q for the input driver. For a ribbon-beam cathode the cathode and resonant coupler are divided lengthwise into segments of equal length. The metalized inductor is fabricated separately and bonded to the gate layers of C_1 and C_2 by conventional ultrasonic bonding. Each resonant circuit is capacitively coupled (C_c) to an impedance matching network which matches rf power from a waveguide into the sequence of input couplers.

Knife-Edge Chamber

We have applied the basic design concepts of the gigatron cathode to devise a promissing new technology for precision track chambers for SSC detectors. Present track chamber technologies (proportional chambers, silicon microstrip chambers, scintillating fibers) all fail to achieve the performance required for tracking particles in SSC spectrometers: spatial resolution (20 μm), live time (15 nsec), and radiation hardness (10 Mrad).

We have devised a proportional chamber[5] in which the anode plane consists of a silicon substrate on which a pattern of knife edges and field-shaping electrodes are fabricated as shown in Figure 8. The fabrication follows closely the procedures developed for the gigatron cathode. When configured with a planar cathode and filled with an appropriate Xe gas mixture, the device forms a microscopic version of a multi-wire proportional chamber (MWPC), with "wire" spacing 50 μm and gas gain 10^4.

The knife-edge chamber uniquely offers attractive performance for the track chambers required for SSC detectors, for which no present technology is yet satisfactory. Its features include:

- o excellent radiation hardness - >10 Mrad
- o excellent spatial resolution - ~25 μm
- o short drift time - ~10 nsec
- o large pulse height - ~1 mV
- o possibility to make fast clearing of ions
- o segmentation and stereo along axial coordinate
- o potential for modest cost ~10 ¢ per channel.

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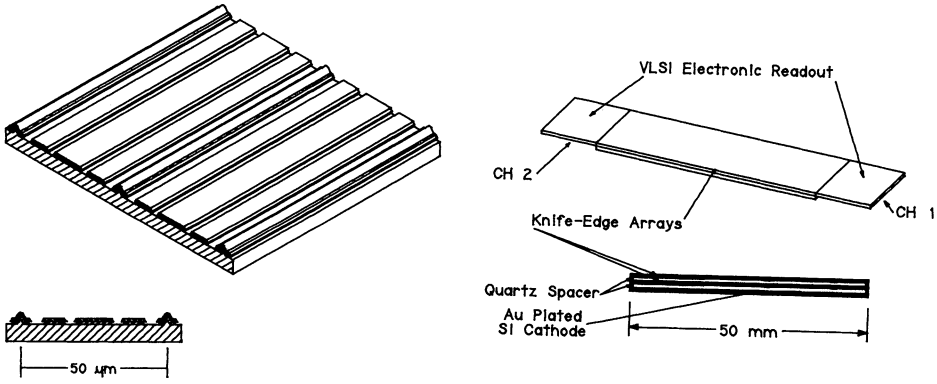

8. (a) Knife-edge array on silicon substrate;
(b) assembly of knife-edge chamber and readout electronics.