FIRST LASING FROM A HIGH POWER CYLINDRICAL GRATING SMITH-PURCELL SOURCE

Hans Bluem, Jonathan Jarvis, and Alan M.M. Todd

Advanced Energy Systems, 100E Forrestal Rd., Princeton, NJ 08540 USA

Robert H. Jackson,

Greensboro, NC 27455 USA

Jacques Gardelle and Patrick Modin

CEA/CESTA 33116 Le Barp, France

John T. Donohue

Centre d' Etudes Nucleaires de Bordeaux-Gradignan,
University of Bordeaux, CNRS/IN2P3, BP 120, 33175 Gradignan, France

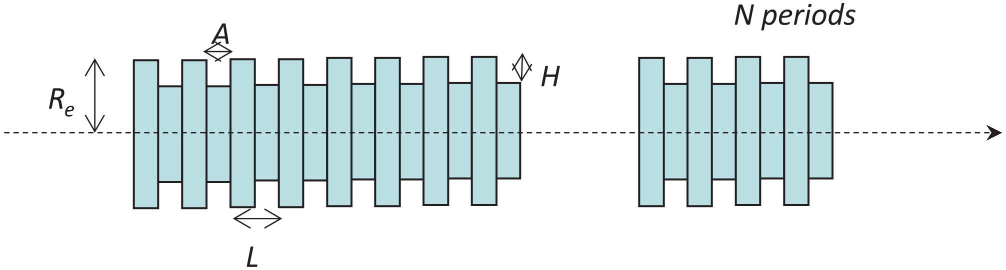
* Work supported by US Department of the Navy, Office of Naval Research under Contract No. N00014-10-C-0191 and Grant No. N62909-13-1-N62

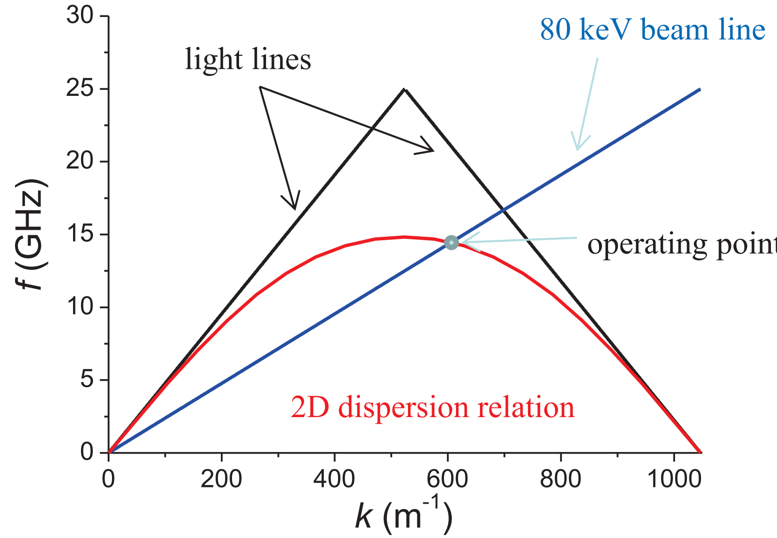
Introduction

- Fully electromagnetic particle-in-cell simulations predict that an annular electron beam coupled to a cylindrical grating is capable of generating high-power THz radiation in a compact package.
- Cylindrical geometry is compatible with well-established magnetic focusing technology and allows a significant increase in total power
- The grating surface-wave yields strong beam bunching resulting in significant radiated power at the fundamental and harmonic frequencies
- Advanced Energy Systems and CEA/CESTA are collaborating on proof-of-principle experiments to validate the potential of cylindrical grating configurations as high-frequency sources.
- **Initial tests at 5 GHz, subsequent tests with 6 mm period grating have generated significant power at 15 GHz (fundamental) and 30 GHz (2^{nd} harmonic)**
- Comparisons between simulations and experimental results will be presented
- A planned experiment at 100 GHz (fundamental) and 200 GHz (2^{nd} harmonic) will be discussed

Parameters of Grating and Dispersion Relation

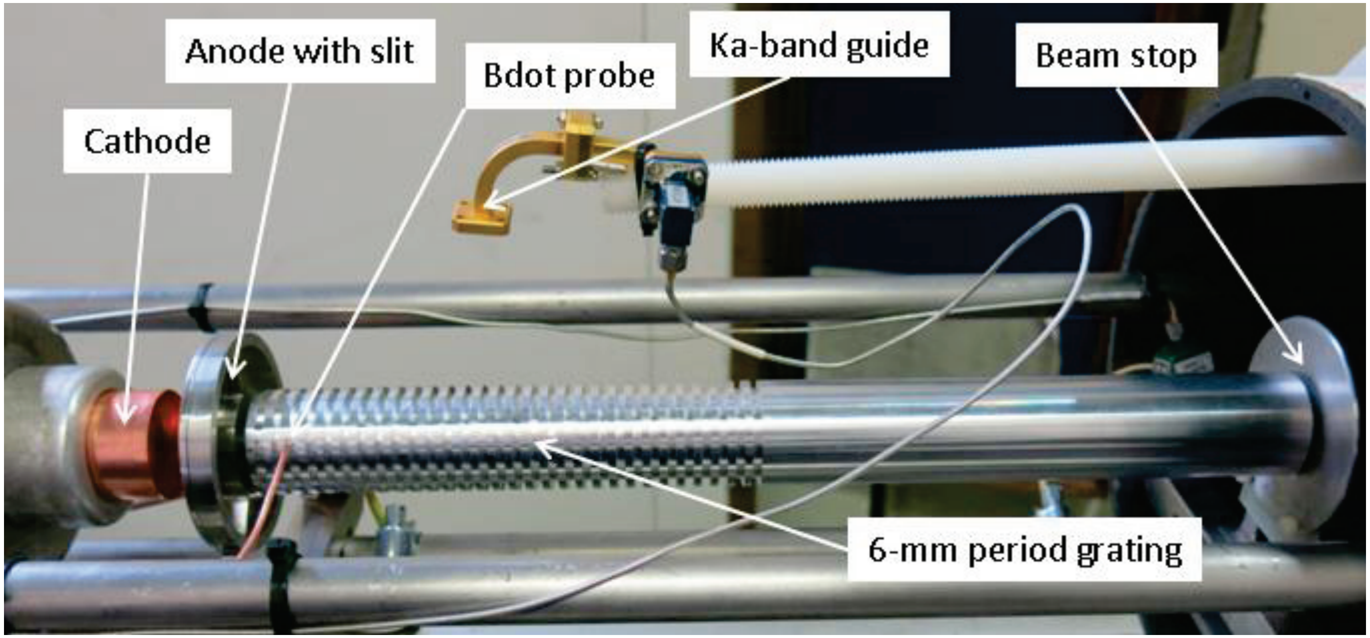
L = 6 mm
A = 3mm ; H = 3mm ;
R_e = 19,25 mm ; R_i = 16,25 mm
N = 30





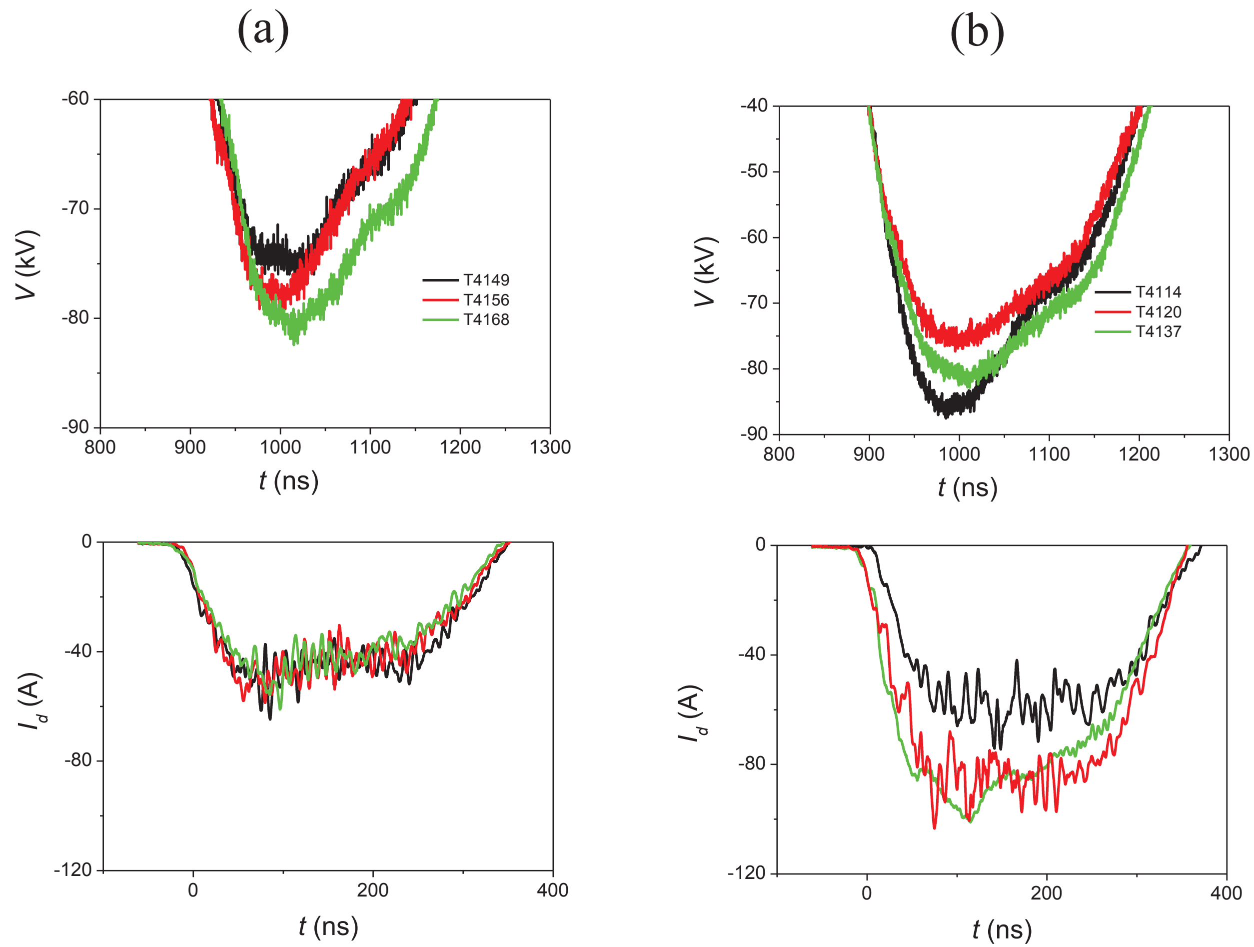
2D-dispersion relation (red) along with the 80 keV beam line (blue) and light lines. The operating point is indicated.

Experimental Setup with 6 mm Grating



Photograph of grating installed in the experiment at CESTA

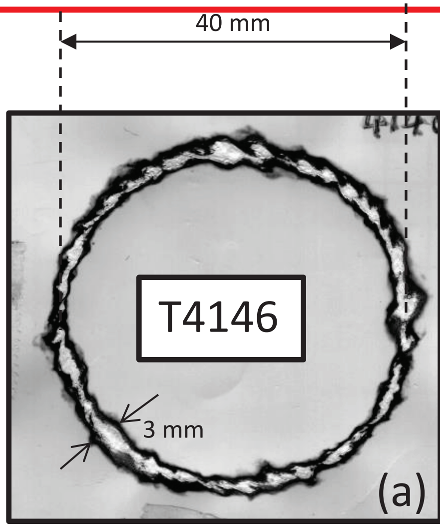
Typical Voltage and Current Measurements



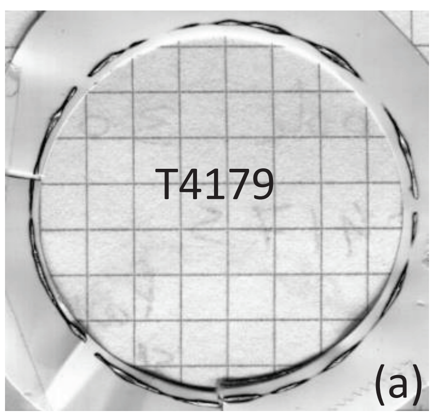
Examples of beam voltages and collected currents.
(a)slit 0.5 mm, (b) slit 1mm.

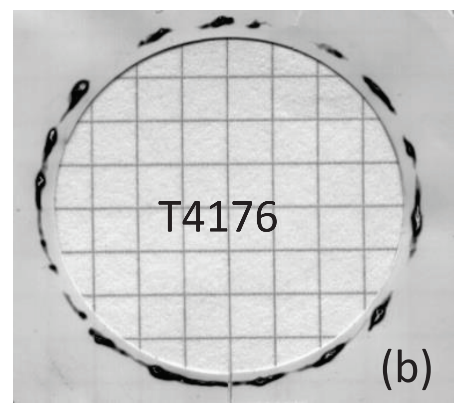
Total current before slit 500-600 A

Beam Profile Images



Beam imprints on thermal paper
a) at the anode plate, b) backside illumination of the slit with imprint of the beam.





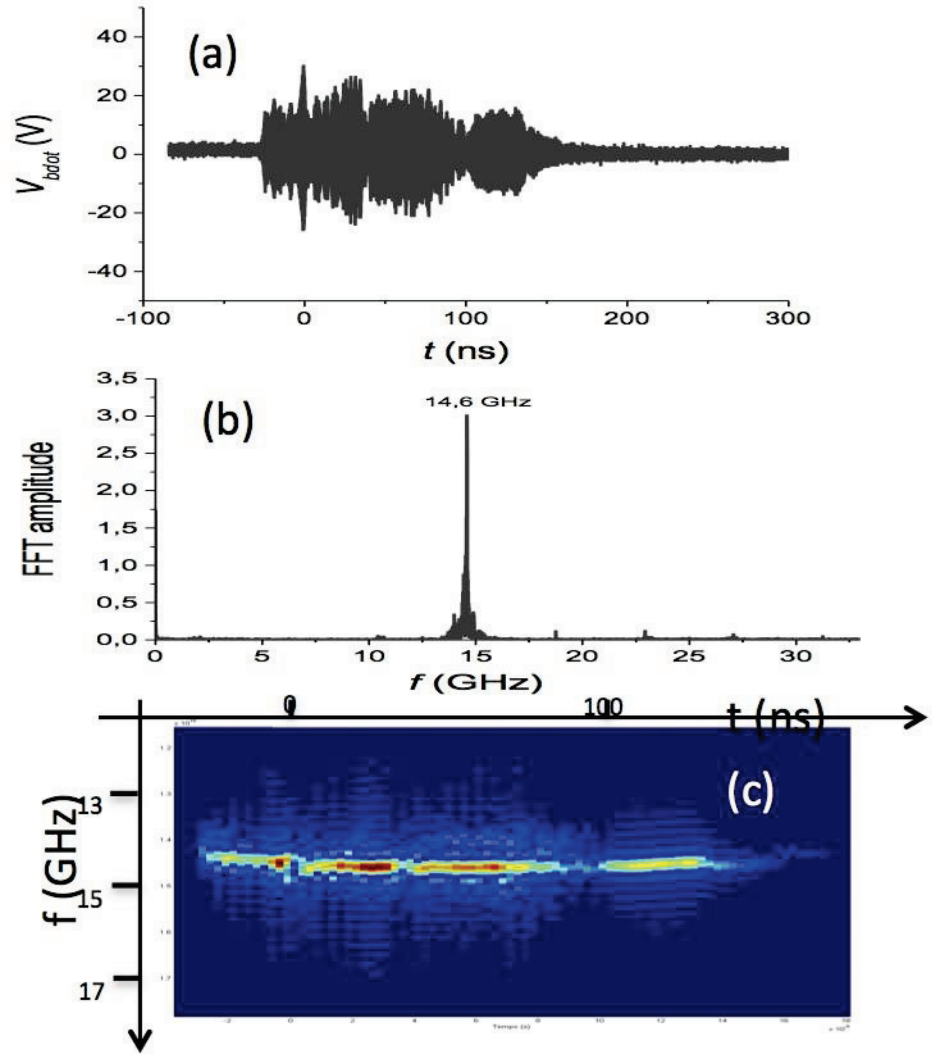
Beam imprint showing improved alignment
a) Just behind anode plate, b) at the dump for a slit thickness of 0.5 mm

Fundamental Mode Results and Analysis

- Sensitivity of loop is

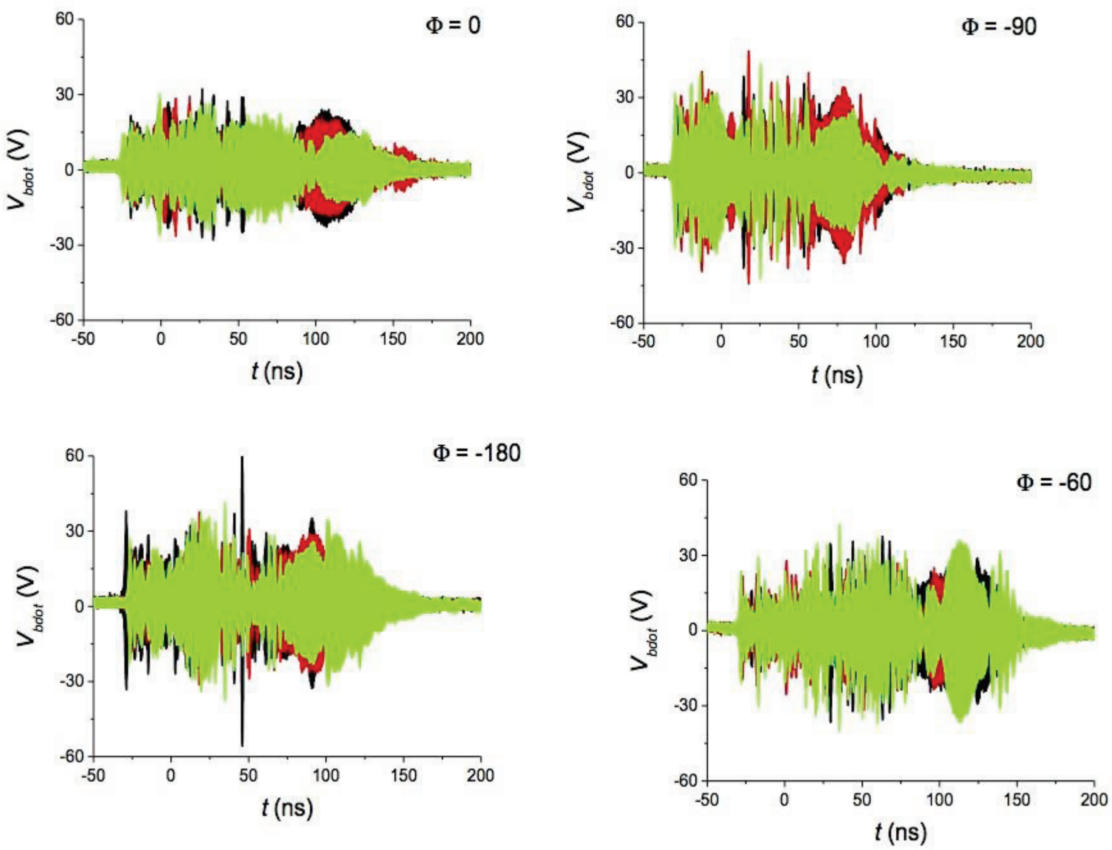
$$\eta = \frac{V}{B_\phi} = \frac{j\omega S}{1 + \frac{jL\omega}{Z}}$$

- Estimated magnetic field at loop is 17 G



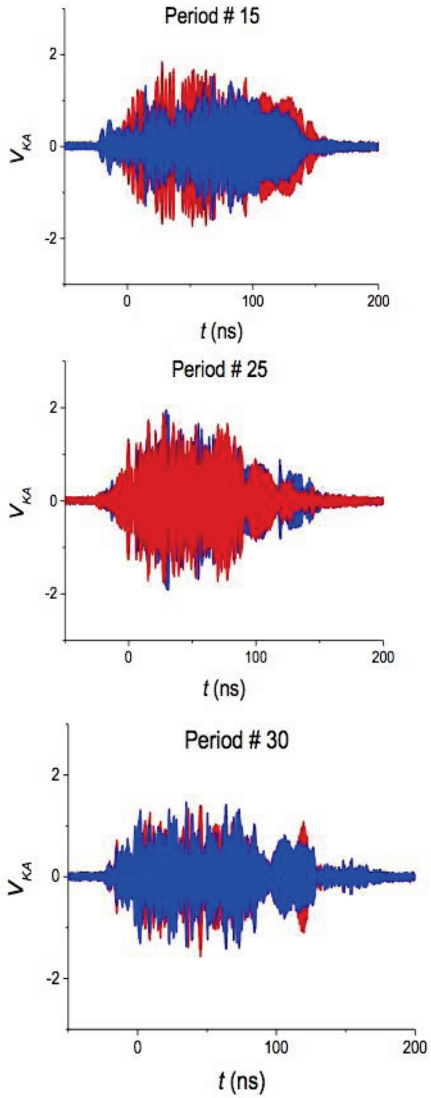
Typical B-dot signal.
(a)Voltage , b) FFT spectrum and c) sliding FFT.

Fundamental Mode Results and Analysis

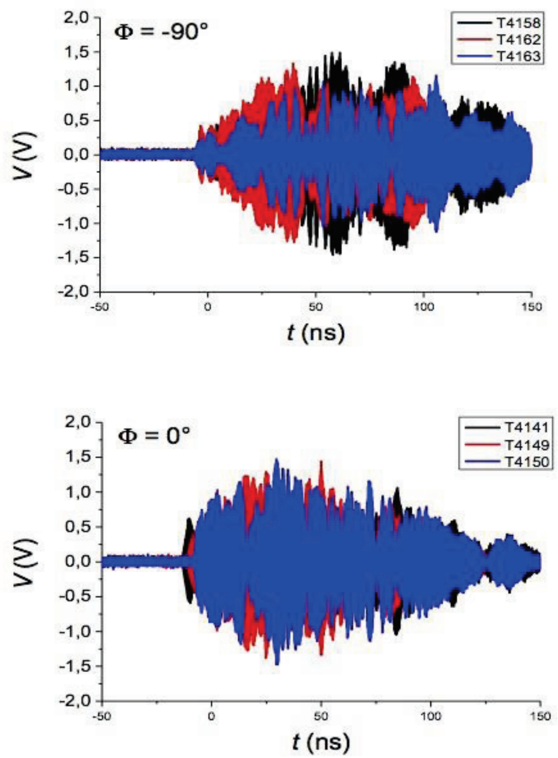


B-dot signals obtained by moving the B-dot around the axis with an angle Φ.
The loop is located at 3 mm above groove # 3.

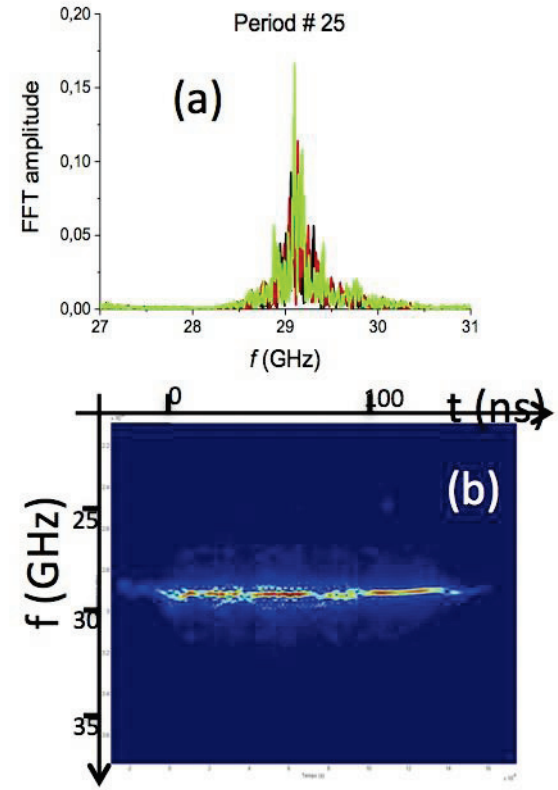
Second Harmonic CSP Results and Analysis



Ka-guide signals at three positions in z above the grating.

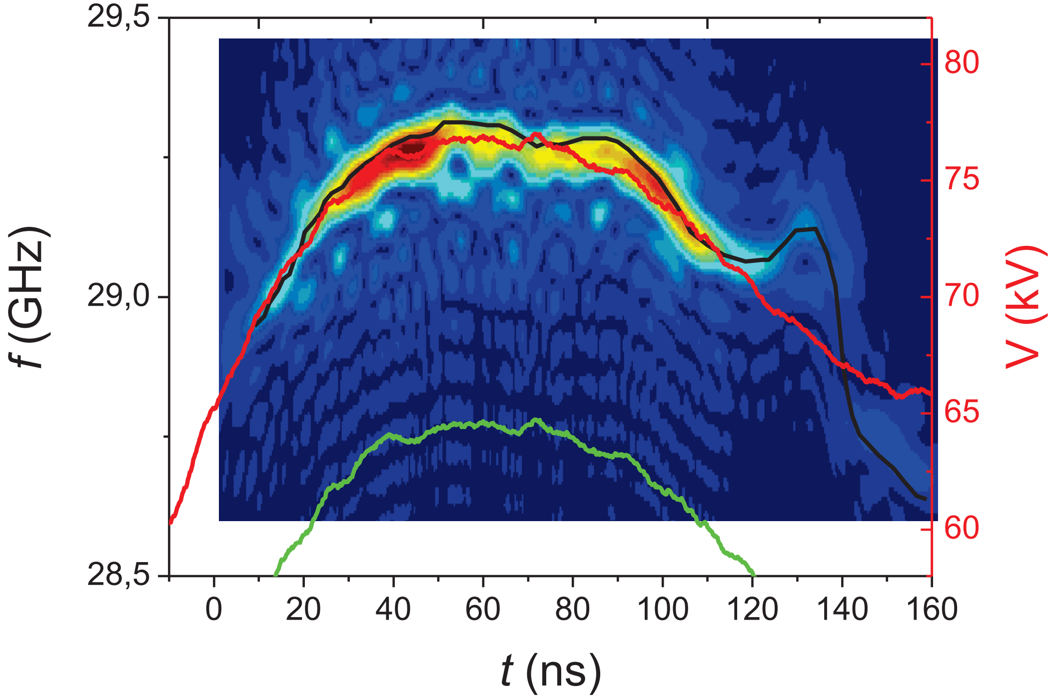


Ka-guide signals obtained above period # 15 for two positions around the axis.



(a) FFT of three Ka-guide signals obtained above period 25.
(b) sliding FFT for one of them.

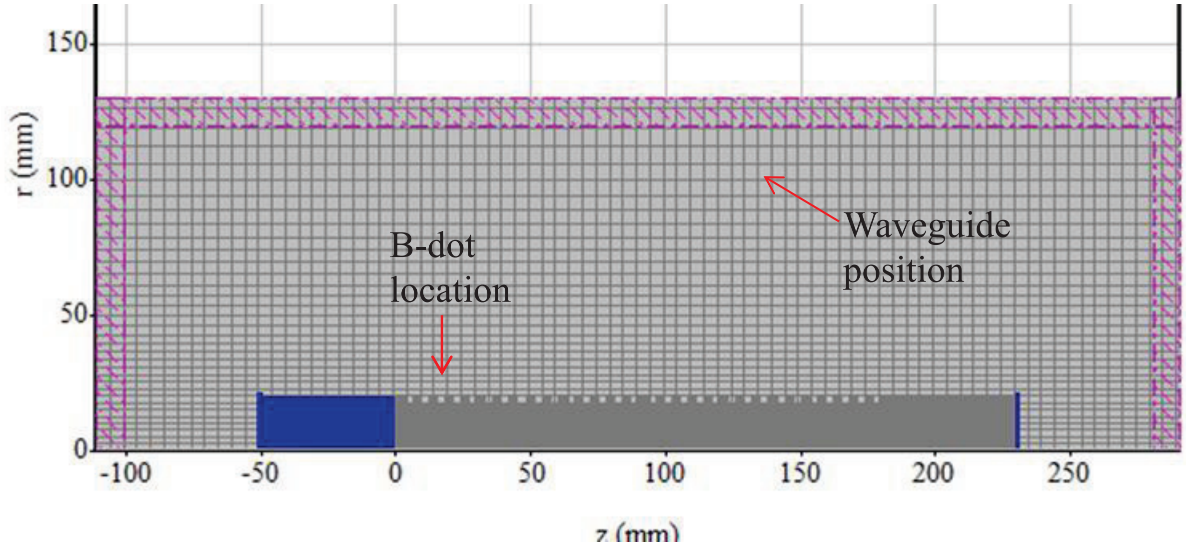
Second Harmonic CSP Results and Analysis



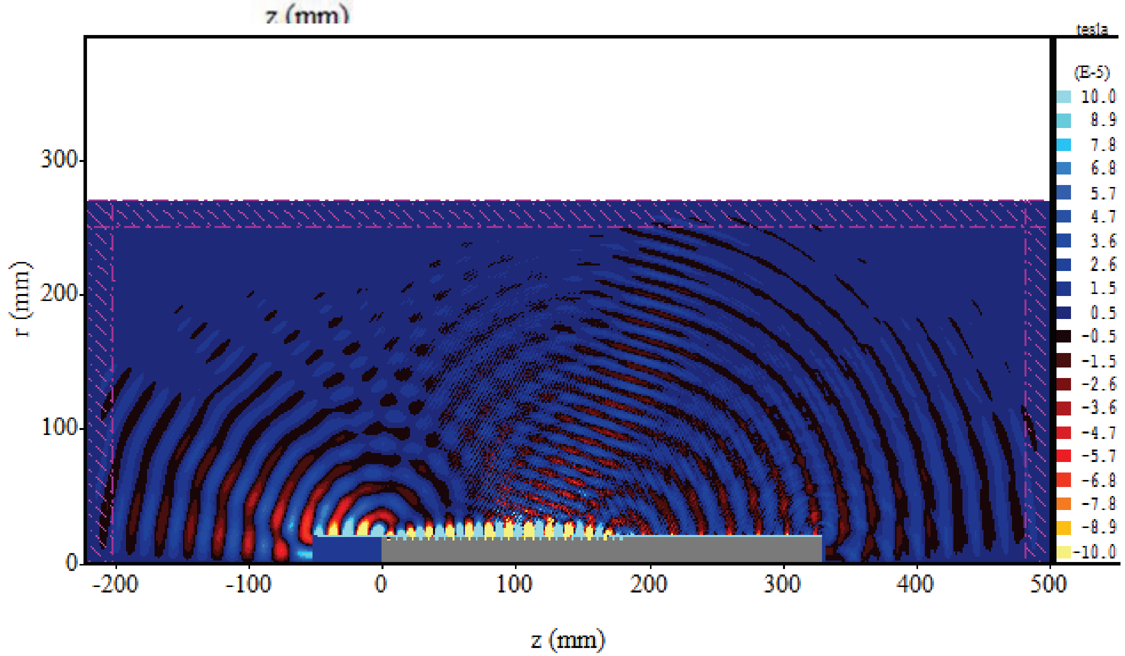
Evolution of the CSP frequency vs beam voltage: the green curve is $2f\,(V)$ from dispersion relation

Estimated power contained in CSP wave in experiment is 10 kW where as the values derived from the MAGIC simulations is 5 kW

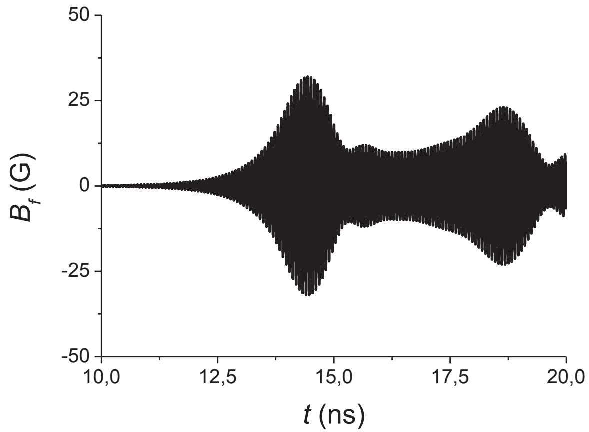
MAGIC 2D Simulations

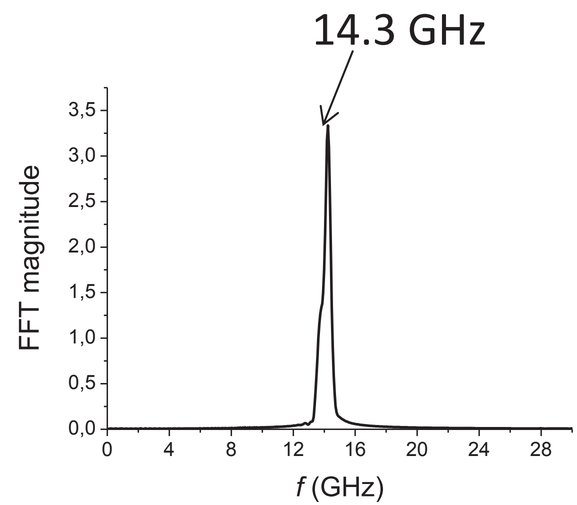


•Can observe
- fundamental evanescent backward wave at 15 GHz
- scattered fundamental
- CSP emission at 30 GHz



MAGIC Fundamental Mode Results





Azimuthal magnetic field at a point representing the middle of the B-dot probe in groove#3 from MAGIC simulation

Simulation shows maximum magnetic field at position of B-dot probe is 30 G compared to the experimental estimate of 17 G

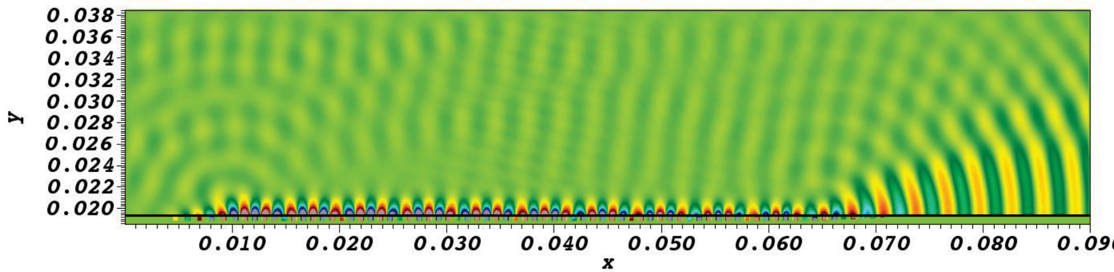
Estimated power in evanescent wave from simulation is 200 kW with a total electron beam power of 3.2 MW

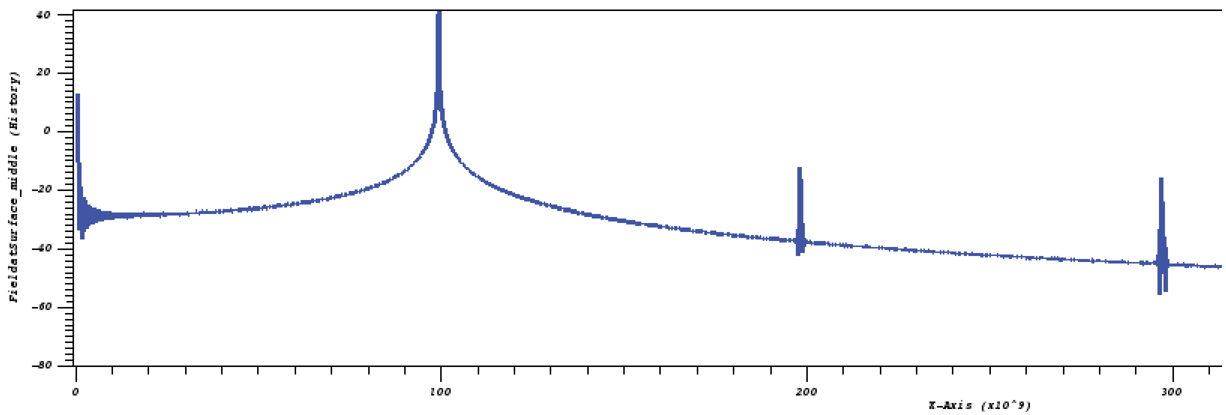
Future Plans

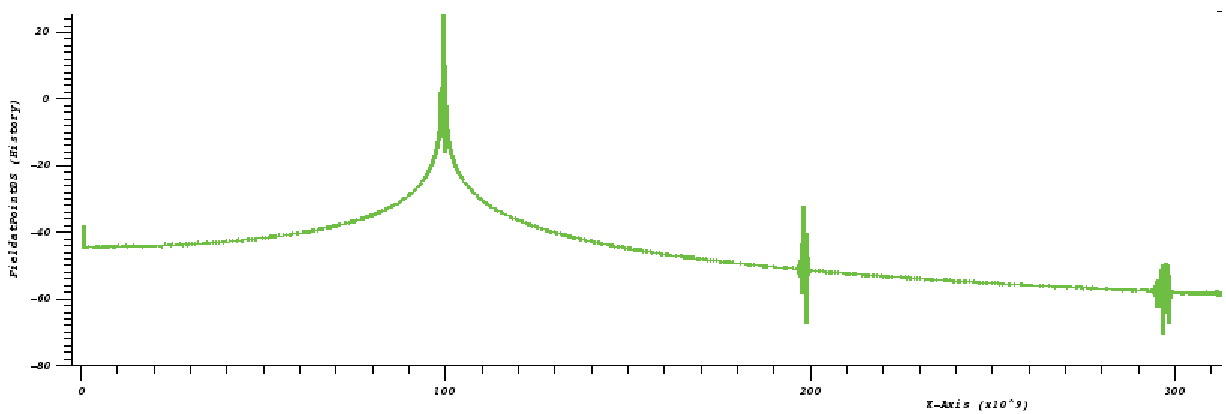
- Next step is a set of experiments demonstrating 100 GHz fundamental with 200 GHz second harmonic
- Power extraction methods for fundamental evanescent wave and second harmonic
- Dual grating configurations
- Exploration of breaking azimuthal symmetry to shift backward wave dispersion curve
- Develop thermionic or field emission cathode system

100 GHz VORPAL Simulations

2D field map of 100 GHz surface wave and 200 GHz CSP







FFT of field at a point near middle of grating (blue) and downstream of grating (green)

Conclusions

- Annular configuration demonstrated to provide high power radiation in simple, compact device

- Set of experiments performed at 15 GHz fundamental frequency with CSP output at 30 GHz
  - Several kW of power estimated at 30 GHz

- Excellent agreement between experimental results and simulations using MAGIC and VORPAL

- Planned experiment at 100 GHz fundamental, 200 GHz 2nd harmonic with simple downstream extraction of fundamental.