High-Power Free-Electron Masers Utilising 2D – 1D Bragg Lasing Cavities

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ABSTRACT: We report the results from a coaxial 2D – 1D Bragg cavity based Free-Electron Maser, utilising a high-current (1.5kA), magnetically confined, thin annular electron beam with circumference of ~220mm, wall thickness of ~2mm and mean radius of ~35mm. The electron beam was transported through a 2m long coaxial drift-tube with inner and outer radii of 30 mm and 40mm respectively. Results obtained via numerical modelling and experimental observation are presented and compared.

GENERATION OF HIGH-CURRENT, LOW- DENSITY, ELECTRON BEAM

For operation, the Free-Electron Maser (FEM) experiment required a ~1.5kA electron beam source, with a low spread in the electron bulk streaming velocity. To this end a high-current diode was developed using the PiC code KARAT [1]; the (r,z) geometry is shown in Fig. 1(a). The diode was azimuthally symmetric, with a bounding anode-can radius of 14.5cm and an annular cathode with a mean radius of 3.5cm. The effective anode plane was formed by the entrance to the co-axial drift tube, 10cm down stream from the cathode emitter. A uniform magnetic field of ~0.65T was applied to confine the radial motion of the emitted electrons, leading to a spread in the axial velocity of the electrons in the region of 1% for applied diode potentials of 300-600kV. Fig. 1(b) compares the numerical estimate of the diode voltage to beam current relation along with the experimentally determined values of the physical diode:

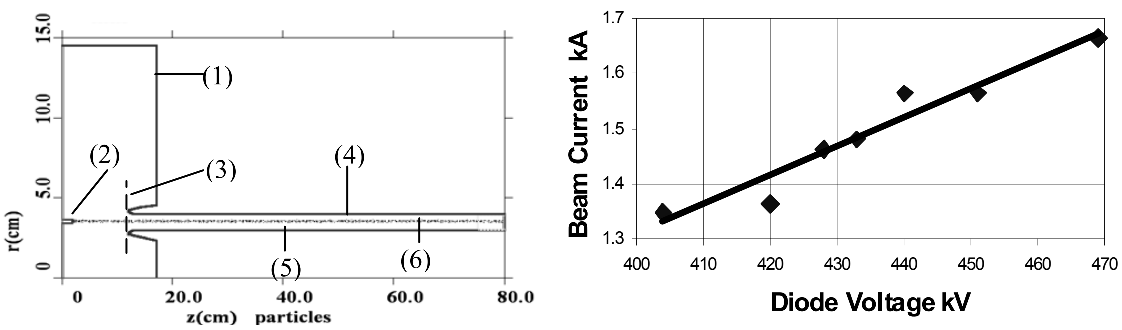

Fig.1 Shows: (a) the KARAT model of the accelerating diode, noting (1) anode-can (2) cathode (3) effective anode plane (4) outer conductor (5) inner conductor (6) electron beam; (b) Compares numerical and experimental values for the beam current.

The experimentally measured beam current was obtained using a differential Rogowski coil located ~30cm into the drift-tube region, in-line with the location of the beam current measurements made in the KARAT simulations. The high level of agreement between the expected and measured performance allows an estimate of the current density as being ~300A/cm for an estimated radial spread in the beam electrons of ~2mm, centred at r=35mm. For more detail on the high-current source see [2].

2D–1D FEM DRIVEN BY 1.5kA BEAMS.

The high current beam source was used to drive an over-sized Ka-band (26.4–40GHz) FEM maser, based around a 2D–1D Bragg lasing cavity. Details of the reflectors used to form such cavities may be found in [3-5]. The expected performance from the FEM, driven by the 1.5kA source, was modelled using the PiC code MAGIC [6]. Examples of the (r,z) model geometry and the spectral content of the output microwaves are given in Fig. 2(a) & (b) respectively.

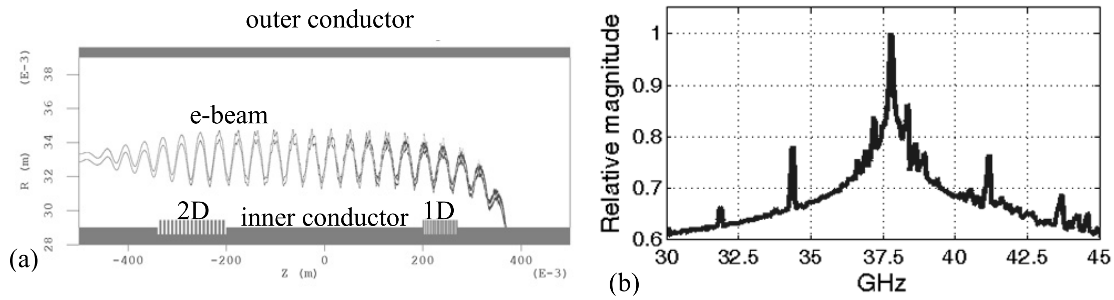

Fig.2 Shows (a) the (r,z) cross-section of the FEM model, (b) the Spectral content of the output microwaves.

The numerical simulations show a central peak in the output microwave content at ~37.5GHz, corresponding to the Bragg resonant frequency of the cavity reflectors, with estimated power outputs in the region of 100MW for beam currents of ~1.5kA, electron energies of ~450keV, a guiding magnetic field strength of ~0.6T and an undulator magnetic field of ~0.06T. The conversion efficiency was ~20%.

The 2D – 1D Bragg cavity was slightly elongated for the FEM experiments to ensure saturation at the cavity output; this was expected to affect the conversion efficiency, however the spectral content of both cavities was expected to be roughly equivalent. This was measured experimentally using high-pass cut-off filters for rough measurement and using a mixer crystal to "mix" the spectral content of the output microwave pulse down to a frequency range observable using a 12GHz bandwidth oscilloscope, allowing for more precise analysis. An example of the measured spectrum, obtained via Fourier analysis of the "mixed" signal of a pulse from the FEM, is shown in Fig. 3:

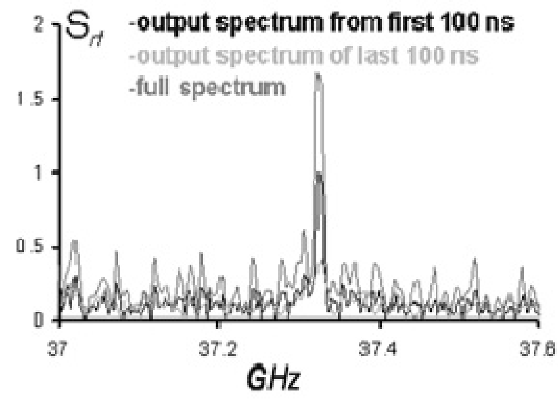

Fig. 3 Shows the spectral content of a microwave pulse from the 2D – 1D Bragg FEM

Best performance was noted using a beam current of ~1.3kA at electron energies of ~440kV, guide field strength of ~0.56T and an undulator field of ~0.06T. This generated ~60MW mean power in the microwave pulses with durations of ~ 150ns and conversion efficiencies of ~10%:

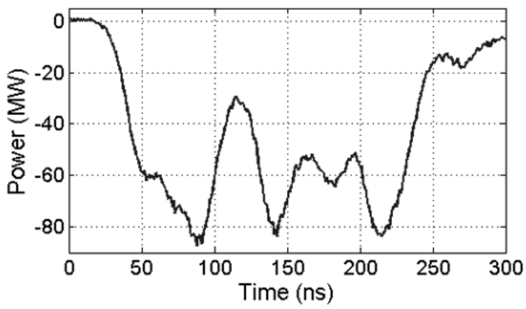

Fig.4 Shows a microwave pulse from the 2D – 1D Bragg FEM, driven by the high-current source.

CONCLUSION

A high-power Ka-band FEM, utilising a 2D – 1D Bragg lasing cavity, has been designed, constructed and experimentally verified as capable of producing single frequency microwave pulses at ~37.3GHz, containing ~60MW of power (~10J) in the pulse. Further detail on the FEM experiment and its current performance can be found in [7], which includes additional work, carried out at higher beam currents of ~4kA, using a similar cavity design.

References.

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