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ABSTRACT

We present the design of a 250 GHz, 400 MW Cyclotron Auto Resonance Maser (CARM) oscillator driven by a 1 KA, 2 MeV electron beam produced by the induction linac at the ARC facility of LLNL. The oscillator circuit is designed as a feedback amplifier operating in the TE_{11} mode at ten times cutoff terminated at each end with Bragg reflectors. Theory and cold test results are in good agreement for a manufactured Bragg reflector using 50 μm corrugations to ensure mode purity. The CARM is to be operational by February 1990.

INTRODUCTION

The CARM is of considerable interest at LLNL because of its potential for providing high peak powers and frequencies required for plasma heating. It operates as a doppler upshifted gyrotron in a strong axial guide field at a wavelength given by: $\lambda = \lambda_c[1 + (\gamma\beta_\perp)^2]/\gamma^2$ where λ_c is the cyclotron wavelength and $\beta_\perp$ is the rotational velocity. This formula is indentical to that for an FEL when the wiggler period λ_w is substituted for λ_c. At lower electron energies ($\lesssim$4 MeV) the CARM can achieve much higher frequencies than the FEL since λ_c can be made much smaller than λ_w.

We have designed a proof-of-principle Induction Linac Driven CARM oscillator experiment at 250 GHz to be performed on the ARC facility at LLNL. Figure 1 shows a schematic of the basic design. The electron beam is generated from a 1 KA, 2 MeV Pierce-type induction linac injector using a thermionic cathode. The beam is focussed into a 10 kG field at a diameter of 4.6 mm. The beam is run in an immersed flow configuration (4.5 times Brillouin) in order to minimize beam rotation which causes increased transverse velocity spread. The beam is then sent through a bifilar wiggler field where it acquires some uniform rotational energy. Finally the beam is compressed into a 29 kG field and enters the interaction region. A quasi 3D beam dynamics code including space charge is used to model the corkscrew beam from the wiggler to the circuit. The CARM oscillator circuit is designed as a saturated feedback amplifier operating in the TE_{11} mode at ten times cutoff. The circuit consists of a straight interaction region with feedback provided by Bragg reflectors at each end. A self-consistent nonlinear particle field code models the CARM interaction. Results of the saturated circuit performance predicted from this code are illustrated in Figure 2. The final beam line and circuit design parameters are given in Tables I and II. The reflection and linear gain must be sufficiently high so that the fill time is less than the pulse time (30 ns).

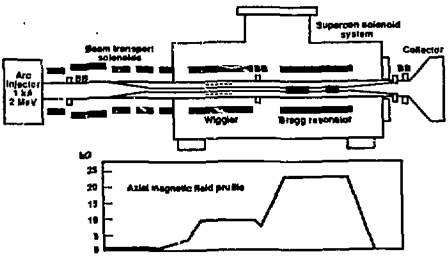

Figure 1. Schematic of proposed CARM Oscillator Experiment

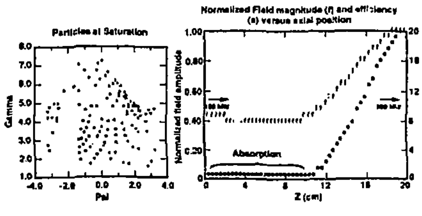

Figure 2. Predicted circuit performance of 250 GHz CARM feedback amplifier. Net output power is 400 MW, magnetic taper is 4%.

Table I (Beam Line Design)

Voltage	2 MeV
Current	1 kA
Beam radius (circuit)	0.24 cm
Cathode radius	6.3 cm
Cathode axial field	13 Gauss
Wiggler axial field	10 kG
Wiggler transverse field	45 Gauss
Wiggler pitch	5.1 cm
Circuit magnetic field	29 kG
Velocity ratio alpha	0.3
Transverse velocity spread	5%

Table II (Circuit Design)

Frequency	250 GHz
Mode	TE_{11}
Circuit radius	0.35 cm
Circuit length	20 cm
Output Bragg reflector	3.3 cm (20% refl)
Input Bragg reflector	18 cm (88% refl)
Ripple amplitude	25 μm
Ripple wavelength	0.06 cm
Non-Linear gain	7 db
Linear gain	12.6 db
Fill time	23 ns
Efficiency	20%
Net output power	400 MW

DESIGN OF BRAGG REFLECTOR

The oscillator circuit requires Bragg reflectors to provide the correct feedback thus building up the field to the desired saturated values. The output Bragg reflector has a reflection coefficient of 20% while the reflection coefficient of the one closest to the injector should ideally be near 100%. Since the Bragg resonator circuit is designed ten times above cutoff in order to handle high average power, the forward TE_{11} mode can couple to both the backward TE_{11} and TM_{11} wave simultaneously. The Bragg reflector must be designed using a four mode coupled theory for forward and backward TE_{11} and TM_{11} waves given by the following equations.

$$\frac{d}{dz}\begin{bmatrix} A^+_{TE} \\ A^-_{TE} \\ A^+_{TM} \\ A^-_{TM} \end{bmatrix} = \begin{bmatrix} -i\Delta_E & -iG_E & 0 & -iG_p \\ iG_E & i\Delta_E & iG_p & 0 \\ 0 & -iG_p & -i\Delta_M & -iG_M \\ iG_p & 0 & iG_M & i\Delta_M \end{bmatrix} \begin{bmatrix} A^+_{TE} \\ A^-_{TE} \\ A^+_{TM} \\ A^-_{TM} \end{bmatrix}$$

where Δ_E and Δ_M are deviation of the TE and TM mode from Bragg resonance and G_E, G_M, and G_p are the TE, TM, and cross coupling coefficients respectively. Figure 3a shows the solution to the above equations for the reflected TE and TM powers as the Bragg ripple amplitude is decreased. The modes become separate only for small ripple amplitude (.001 inch). A Bragg reflector was fabricated with 300, 50 μm corrugations using the LLNL diamond lathe. Insertion loss measurements were made using an impatt diode source operating from 245 GHz to 255 GHz. The results are shown in Figure 3b plotted against the theoretical predictions for insertion loss (i.e., transmitted TE_{11} power). There is excellent agreement between theory and cold test results.

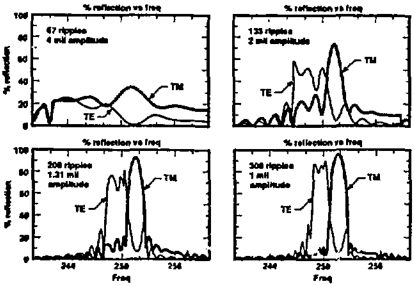

Figure 3a. Reflected power in TE and TM mode vs frequency

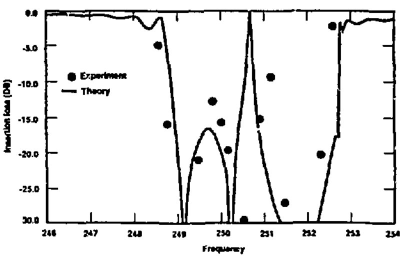

Figure 3b. Transmitted power in TE_{11} mode vs frequency, theory vs experiment.

FUTURE PLANS

Beginning October 1989, the rest of the beam line components, magnets and microwave tank will be fabricated. The superconducting magnet and microwave diagnostics are being provided by UCLA and MIT. Testing is scheduled to begin February 1990.

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