Oversized W-band 2D Periodic Lattice Oscillator

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***Abstract*—To mitigate the conventional scaling of slow-wave vacuum electronic oscillators, in which the maximum output power reduces as the frequency increases, an oversized cylindrical structure is driven by an annular electron beam. To enhance mode selectivity a two dimensional (2D) periodic lattice structure (PSL) is used. The 2D PSL consists of shallow periodic cosinusoidal perturbations in both the azimuthal and axial directions on the inner wall of a cylindrical waveguide. Analytical theory and numerical PIC simulations have been used to design the W-band oscillator that has been constructed. The ratio of the diameter of the cylindrical cross-section of the structure to the operating wavelength is ~5. The performance of this oscillator is being measured and compared with the predictions of the numerical simulations.**

Keywords—2D periodic lattice, W-band, oscillator, mm-waves

I. Introduction

The advantages provided by the application of periodic lattice structures in vacuum electronic microwave sources has been of growing interest [1-11]. Two dimensional (2D) periodic surface lattices PSLs have been used successfully in both fast-wave sources [2] and in slow-wave sources [5-14], although the details of the physical interactions that are involved differ in the two cases. In the present work the focus is on a slow wave interaction in the W-band (75-110 GHz).

II. Theory

A hollow conducting cylindrical waveguide with shallow periodic cosinusoidal perturbations in both the azimuthal φ and axial z directions on the inner wall is described by the equation,

$$r = r_0 + \Delta r[\cos(m\varphi)\cos(k_z z)] \quad (1)$$

where m is the number of azimuthal variations, r_0 is the mean radius of the waveguide, Δr is the amplitude of the perturbation, and $k_z=2\pi/dz$, where dz is the period of the perturbation along the axial z-coordinate.

The diameter of the waveguide ($D = 2r_0$) is able to be made much larger than in traditional slow wave devices. In the present work the cylindrical cavity is oversized to the extent that D/λ~5, where λ is the wavelength of the W-band radiation. A near cut-off $TM_{0,n}$ volume mode facilitates wave synchronization.

A series of cases with a range of initial parameters have been numerically modelled using the CST Studio software suite. The parameters and dimensions of the 2D PSL configuration, the radial position of the annular electron beam, its accelerating potential in steps from 60 kV to 90 kV and current values ranging between 100 A and 200 A have been used as inputs to the numerical model. The results of the modelling show that, as expected, such a highly overmoded interaction structure is sensitive to relatively small changes in the input parameters.

Outputs at ~95 GHz of MW level with over 10% electronic efficiency are predicted by the modelling with appropriately chosen values of the length of the 2D PSL interaction region and with optimum selected 2D PSL parameters r_0, Δr, dz, and m.

III. Experiment

W-band 2D PSL interaction structures have been constructed using two manufacturing methods (1) electrochemical deposition of copper on a cylindrical aluminum former with the aluminum subsequently removed by dissolving in strong alkali solution and (2) a 3D additive manufacturing (3D printing) technique resulting in a silver/chromium cylindrical 2D PSL. The structure used in the experimental program that is being reported here has used method (1). An earlier experiment [12] used the 3D additive manufacturing method. The computer numerically controlled (CNC) machined aluminum former is shown in Fig. 1 and the outside of the electrochemically deposited copper structure is shown in Fig. 2.

A sharpened annular graphite cathode is used to provide the annular electron beam source. The electron beam of ~100 ns pulse duration that can be varied over the accelerating voltage range from 60 kV to 90 kV, is guided by a strong axial magnetic field provided by a superconducting magnet and is passed through the cylindrical 2D PSL copper cavity. The superconducting magnet is one that has been used in other applications and is capable of supplying a magnetic field that can be systematically varied up to 11 tesla, although the magnetic field needed to provide electron beam transport through the cylindrical 2D PSL structure in the present experimental program is only a few tesla. The diagnostics available to characterize the electron beam include Faraday cup, witness plate and macroscopic current/voltage measurements. The mm-wave diagnostics include cut-off waveguide filters, W-band heterodyne mixer and intermediate frequency capture and analysis, as well as output mode pattern measurements.

The assembled W-band oscillator is shown in Fig. 3. More than one 2D PSL interaction structure has been constructed, so as to be able to change the structure and compare the experimental results with numerical simulations carried out for a range of structure parameters. In order to be able to easily change the 2D PSL structure the vacuum envelope of the oscillator, including the electron gun, the output waveguide, electron beam collector and the output window have been constructed so as to be demountable. The vacuum system is continually pumped and the measured vacuum pressure is ~3×10^{-6} mbar. This pressure is sufficiently low to

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allow reliable production from the sharpened graphite cold cathode of ~100 ns electron beam pulses.

IV. Conclusions

Theory and simulations have enabled the design of an oversized (D/λ~5) W-band 2D PSL oscillator that uses a 2D PSL to provide mode rarefaction in the overmoded interaction structure. In the present research program electrodeposition of copper on an aluminum former has been used to construct the 2D PSL interaction structure. The experiment with its vacuum system, magnet and power supplies has been assembled. The necessary vacuum pressure has been achieved and the experimental program of measurements is underway.

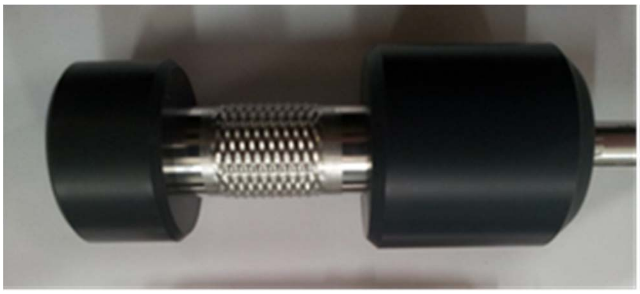

Fig. 1. CNC machined aluminum former.

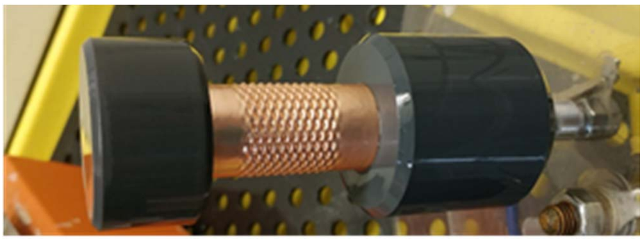

Fig. 2. Electrodeposited copper 2D cylindrical periodic structure.

Fig. 3. Assembled oversized W-band 2D periodic lattice oscillator.

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