Measurements of Structures for Vacuum Electronic Sources Manufactured by 3D Printing

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***Abstract*— Periodic structures that reduce the velocity of electromagnetic wave propagation are widely used in electron beam driven microwave vacuum electronic sources. When the frequency increases into the mm-wave region such structures become difficult to manufacture because of the small physical dimensions. "Additive Manufacturing" or "3D printing" offers the possibility of constructing certain types of components quickly, efficiently and relatively inexpensively. Many questions arise however, including what structural resolution is obtainable, the surface roughness, surface electrical resistivity and vacuum compatibility. To address some of these questions the performance of a periodic structure manufactured using a 3D printing technique and designed for W-band operation (75-110GHz) is evaluated and reported in the present work.**

***Keywords — Additive manufacturing, 3D printing, periodic surface lattice, mm-wave source, W-band*.**

I. INTRODUCTION

"Additive Manufacturing" [1] or "3D printing" offers the possibility of constructing certain types of components quickly, efficiently and relatively inexpensively but many questions arise, including what structural resolution is obtainable, the surface roughness, surface electrical resistivity and vacuum compatibility. To address some of these questions a periodic structure designed to operate as a W-band source (75-110GHz) has been manufactured using a 3D printing technique and is evaluated and reported in the present work.

High power radiation in the millimeter range can be produced using electron beam driven vacuum electronic sources that exploit novel periodic surface structures [2-5]. Subsequent development has allowed MW output powers at frequencies of ~35 GHz [5]. References [2-6] used periodic surface structures in a fast-wave interaction but slow-wave interactions with an electron beam can also be facilitated with an appropriately designed periodic surface structure.

One of the successful methods of constructing periodic surface lattices (PSLs) involves milling sinusoidal perturbations on the outer wall of an aluminum former and electrodepositing copper directly onto the surface [7-11]. The aluminum is then dissolved in a strong alkaline solution, leaving the copper PSL structure with the perturbations on the inner surface. A 2D PSL was successfully created by this method and good agreement between theoretical predictions [10] and experimental measurement of the properties of the 2D PSL was achieved [11].

II. RESULTS

3D printing, developed in the mid 1980's, demonstrates an ever-increasing number of applications. The tolerances achievable with 3D printing are projected to improve over time as the technology develops, resulting in higher degrees of accuracy. 3D printing is used in the initial creative process that results in structures such as the example shown in Fig. 1. It involves an additive process by which consecutive layers in the x-z plane are deposited sequentially in the +ve y direction. The printing process follows the pattern in a given CAD input file, usually in the STL (Stereolithograph) file format where every face is built from a series of interconnected triangles represented by 3 separate 32-bit floating-point Cartesian coordinates. The physical parameters of the W-band (75-110GHz) 2D PSL are shown in Table 1. The design is sliced into digital layers so that a curve is 'approximated' by many square-sided slices, with the thickness of each layer representing the resolution of that particular 3D printing process.

The cylindrical 2D periodic structure can be described by equation (1)

$$r = r_0 + \Delta r \cos(k_z z + m\phi) \qquad (1)$$

where r_0 is the radius of the unperturbed waveguide, Δr is the amplitude of the corrugation, $k_z = 2\pi / d_z$, where d_z is the period of the corrugation over the z - coordinate and m is the number of azimuthal variations of the corrugation.

TABLE I. THE PHYSICAL PARAMETERS FOR THE 2D PSL

Longitudinal Period	d_z	1.6 mm
Azimuthal Variations	m	7
Number of Longitudinal Periods	x	16
Perturbation Amplitude	Δr	800 microns
Mean Radius	r	4.4 mm

The perturbation amplitude is 800 microns (1.6mm peak to peak). Representation of this structure with layers of 16 microns results in a reasonable level of accuracy and the finished component appears to hold an adequate level of

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Part of this work has been sponsored by AFOSR under grant number FA8655-13-1-2132. The postgraduate research studentships of A. R. Phipps and A. J. MacLachlan were sponsored by the Engineering and Physical Sciences Research Council (EPSRC), UK.

detail. In the case of this specific piece the complete part was printed in wax and this former was then used to create a suitable mold into which a molten silver (92.5%) chromium (7.5%) alloy was set, with the resultant component having an overall final resolution within ± 125 microns.

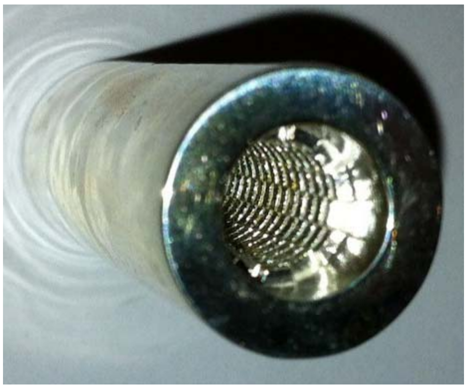

Fig. 1. Cylindrical PSL manufactured using 3D printing.

The 2D PSL structure was successfully incorporated in a cold test system with the transmission of millimeter waves measured using a Vector Network Analyzer (VNA). When testing the structure using the VNA the interaction uses an electromagnetic wave that interacts with the 1.6 mm longitudinal period to give a response in G-band, resulting in a resonance at 187.7GHz, as shown in Fig. 2. The electromagnetic wave when interacting with the 3.5 mm azimuthal period gives a *fundamental* resonance in W-band at ~85 GHz and a resonance at the 1st harmonic at 171.1 GHz in G-band. This is what gives the 171.1 GHz resonance shown in the VNA measurement.

The response of the structure has been measured in the G-band (140-220 GHz) to test the performance of the structure and to verify that both the longitudinal and azimuthal periodicities have been correctly manufactured. The electron beam driven 2D PSL is a W-band structure from the point of view of the frequency of the output of the radiation source. It is because the electron beam is travelling in this case at about half the speed of light and it is the electron beam when operating as a source that is exciting the longitudinal structure in W-band. The corresponding *fundamental* azimuthal resonant electromagnetic response, as noted above, is in W-band and is designed to correspond with the electron beam excitation of the longitudinal structure in W-band.

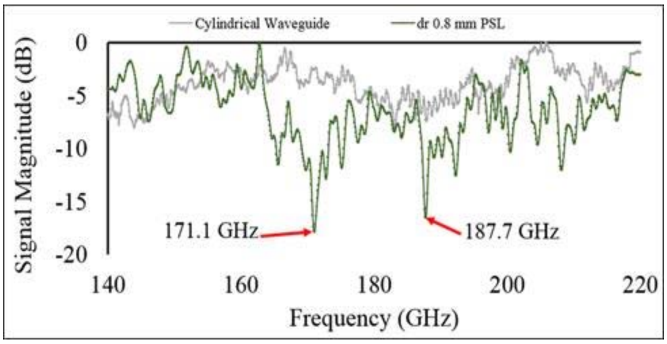

Fig. 2. Measured transmission of cylindrical PSL as a function of frequency.

Following VNA characterization measurements the 3D printed 2D PSL structure has been incorporated into a vacuum electronic source. In initial experiments, using an 80kV annular [12] electron beam, approximately 30 kW of output radiation in W-band has been measured.

III. SUMMARY

This paper demonstrates that additive manufacturing is now becoming relevant for some of the applications in vacuum electronics and can complement conventional engineering processes. 3D printing is emerging as a viable way of producing certain types of microwave structures [13]. As the technology develops the level of accuracy and overall performance that this process offers is likely to increase.

ACKNOWLEDGMENT

The authors thank David Barclay for his technical assistance.

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