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Accession number:13028728

Title:0.22 THz wideband sheet electron beam traveling wave tube amplifier: cold test measurements and beam wave interaction analysis

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Source title:Physics of Plasmas
Abbreviated source title:Phys. Plasmas (USA)
Volume:19
Issue:9
Publication date:Sept. 2012
Pages:093110 (8 pp.)
Language:English
ISSN:1070-664X
CODEN:PHPAEN
Document type:Journal article (JA)
Publisher:American Institute of Physics
Country of publication:USA
Material Identity Number:AV41-2012-011

Abstract:In this paper, we describe micro-fabrication, RF measurements, and particle-in-cell (PIC) simulation modeling analysis of the 0.22 THz double-vane half period staggered traveling wave tube amplifier (TWTA) circuit. The TWTA slow wave structure comprised of two sections separated by two sever ports loaded by loss material, with integrated broadband input/output couplers. The micro-metallic structures were fabricated using nano-CNC milling and diffusion bonded in a three layer process. The 3D optical microscopy and SEM analysis showed that the fabrication error was within 2-3 μm and surface roughness was measured within 30-50 nm. The RF measurements were conducted with an Agilent PNA-X network analyzer employing WR5.1 T/R modules with a frequency range of 178-228 GHz. The in-band insertion loss (S_{21}) for both the short section and long section (separated by a sever) was measured as ~-5 dB while the return loss was generally around ~-15 dB or better. The measurements matched well with the S-matrix simulation analysis that predicted a 3 dB bandwidth of ~45 GHz with an operating frequency at 220 GHz. However, the measured S_{21} was ~3 dB less than the design values, and is attributed to surface roughness and alignment issues. The confirmation measurements were conducted over the full frequency band up to 270 GHz employing a backward wave oscillator (BWO) scalar network analyzer setup employing a BWO in the frequency range 190 GHz-270 GHz. PIC simulations were conducted for the realistic TWT output power performance analysis with incorporation of corner radius of 127 μm, which is inevitably induced by nano-machining. Furthermore, the S_{21} value in both sections of the TWT structure was reduced to correspond to the measurements by using a degraded conductivity of 10% International Annealed Copper Standard. At 220 GHz, for an elliptic sheet electron beam of 20 kV and 0.25 A, the average output power of the tube was predicted to be reduced from 90 W (for ideal conductivity/design S-parameters) to 70 W (for the measured S-parameters/inferred conductivity)

for an average input power of 50 mW. The gain of the tube remains reasonable: ~31.4 dB with an electronic efficiency of ~1.4%. The same analysis was also conducted for several frequencies between 190 GHz-260 GHz. This detailed realistic PIC analysis demonstrated that this nano-machined TWT circuit has slightly reduced S-parameters and output power from design, but within an acceptable range and still have promising output power, gain, and band width as required. Thus, we expect to meet the specifications of 1000 W-GHz for the darpa program goals.

Number of references:19

Inspec controlled terms:diffusion bonding - microfabrication - micromechanical devices - optical microscopy - plasma diagnostics - plasma simulation - plasma-beam interactions - surface roughness - travelling wave tubes

Uncontrolled terms:wideband sheet electron beam - rf measurements - beam wave interaction analysis - microfabrication - particle-in-cell simulation - traveling wave tube amplifier - TWTA slow wave structure - integrated broadband input-output couplers - micrometallic structures - nanoCNC milling - diffusion bonding - 3D optical microscopy - SEM analysis - scanning electron microscopy - fabrication error - surface roughness - S-matrix simulation analysis - BWO scalar network analyzer setup - nanomachining - S21 values - S-parameters - DARPA program goals - MEMS vacuum electronics - frequency 0.22 THz - size 2 mum to 3 mum - size 30 mum to 50 mum - frequency 190 GHz to 270 GHz - gain 3 dB - size 127 mum - power 90 W to 70 W

Inspec classification codes:A5270G Radiofrequency and microwave plasma diagnostic techniques - A5240M Particle beam interactions in plasma - A5265 Plasma simulation - B2350D Travelling wave tubes - B2575D Design and modelling of micromechanical devices

Numerical data indexing:frequency 2.2E+11 Hz;size 2.0E-06 3.0E-06 m;size 3.0E-05 5.0E-05 m;frequency 1.9E+11 2.7E+11 Hz;gain 3.0E+00 dB;size 1.27E-04 m;power 9.0E+01 7.0E+01 W

Treatment:Practical (PRA); Theoretical or Mathematical (THR); Experimental (EXP)

Discipline:Physics (A); Electrical/Electronic engineering (B)

DOI:10.1063/1.4750048

Database:Inspec

IPC Code:B81B; B81C1/00; C09J; G01B9/04; H01J23/00; H01J25/00