Studies on Millimeter-band Low-Voltage Traveling-Wave Tubes with Planar Meander-Line Slow-Wave Structures

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Abstract: *We have designed D-band planar meander-line slow wave structure for low voltage compact traveling-wave tubes (TWTs) with sheet electron beam. The designed D-band slow wave structure was microfabricated by magnetron sputtering and picoseconds laser ablation. We further develop our approach for planar slow wave structure microfabrication based on magnetron sputtering and laser ablation processes. Transmission and reflection losses of proposed SWS were measured experimentally and evaluated numerically. The experimental results are in good agreement with the numerical ones.*

Keywords: Traveling-wave tube; slow-wave structure; W-band; D-band; microfabrication; laser ablation; numerical modeling.

Introduction

Small-sized, high-power vacuum power amplifiers and oscillators operating at millimeter and submillimeter (THz) bands are of great interest for applications in security, non-destructive evaluation, ultra-high-speed information and communication systems, radio astronomy, spectroscopy, medicine, etc. [1,2]. In particular, promising planar slow-wave structures (SWS) utilizing a metallized microstrip line on a dielectric substrate structure have been proposed [3-7]. In [8-10], we reported the results of development of V-band (50-70 GHz) planar meander-line SWS. Such SWSs have high slow-down factor, $c/v_{ph} \sim 5-10$, and thus, are suitable for use in low-voltage traveling-wave tubes (TWTs). Among their other advantages, there are compatibility with the microfabrication technologies, and ability to accommodate a high-aspect-ratio sheet electron beam.

This paper present the results of research aimed at development of TWTs with the meander-line SWS operating at higher-frequency W- and D-band.

SWS Fabrication and Characterization

The W- and D-band planar microstrip SWSs on a quartz substrate were designed and their electromagnetic parameters were evaluated using the finite-element COMSOL Multiphysics simulator. For fabrication of the SWSs, we have developed a cheap, fast, and flexible technology [8-10] based on magnetron sputtering of a metallic film over a substrate and subsequent forming of an SWS pattern by using a computer-numerical-control (CNC) laser ablation. At the final stage the microfabrication process, the substrate is cut into individual SWS samples by using a high-precision diamond scriber with manual positioning.

Using an ytterbium fiber laser with a 1.064-um wavelength and 10-ns pulse duration, we successfully fabricated the W-band structures. However, for fabrication of smaller-size D-band structures, we have to improve the microfabrication process by utilizing the picosecond ablation instead of the nanosecond one. A 10-µm thick copper film was deposited onto 0.2-mm thickness quartz plate by magnetron sputtering. An ytterbium pulse laser with wavelength of 1050-1070 nm and 10-ps pulse duration is used for SWS patterning. Fig. 1 shows a photo of the fabricated D-band SWS and its scanning-electron-microscopy (SEM) image.

The ZVA40 vector network analyzer (Rohde&Schwarz) with frequency converters that convert the frequency range of the vector network analyzer to either W- or D-band is used for the cold-test measurements. Good transmission characteristics values were obtained. The transmission loss S21 of the full-length SWS does not exceed –5 dB while the reflection loss is less than –10 dB. Experimentally measured *S*-parameters are in good agreement with the numerical ones.

Gain Calculations

For the numerical calculations, we use the 1-D nonlinear frequency-domain code [11]. The W-band TWT with a 0.1-A sheet electron beam and 1-cm length SWS was designed

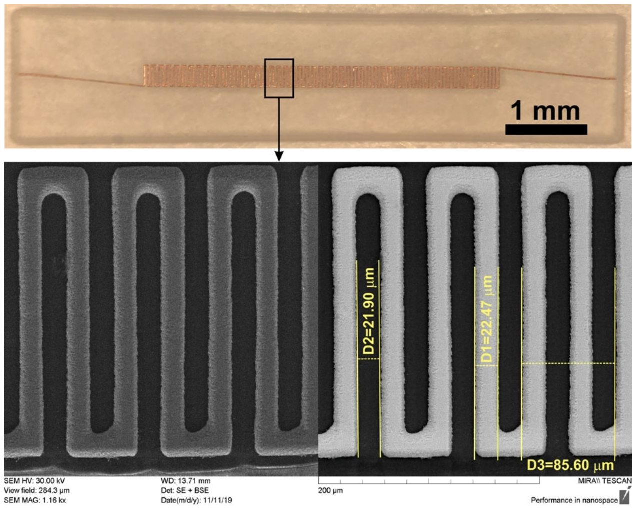

Figure 1. Photo of the fabricated SWS and its enlarged fragment made by scanning electron microscopy in SE and BSE regimes.

and simulated. The simulation predicts over 20 dB small-signal gain and over 80 W power at saturation. The operating beam voltage does not exceed 6 kV. However, owing to strong dispersion of the SWS, the –3-dB gain bandwidth is rather narrow, ~ 3-5 GHz. On the other hand, the central frequency may be easily tuned from 80 to 100 GHz by varying the beam voltage (cf. 8).

For the D-band TWT with 50-mA beam current and 1.75-cm length, up to 27-dB gain is predicted, and the power may exceed 25 W. The results of simulation are presented in Fig. 2.

Acknowledgements

This research is supported by the Cooperative Grant of Russian Foundation for Basic Research (grant 20-57-12001) and DFG (grant 430109039).

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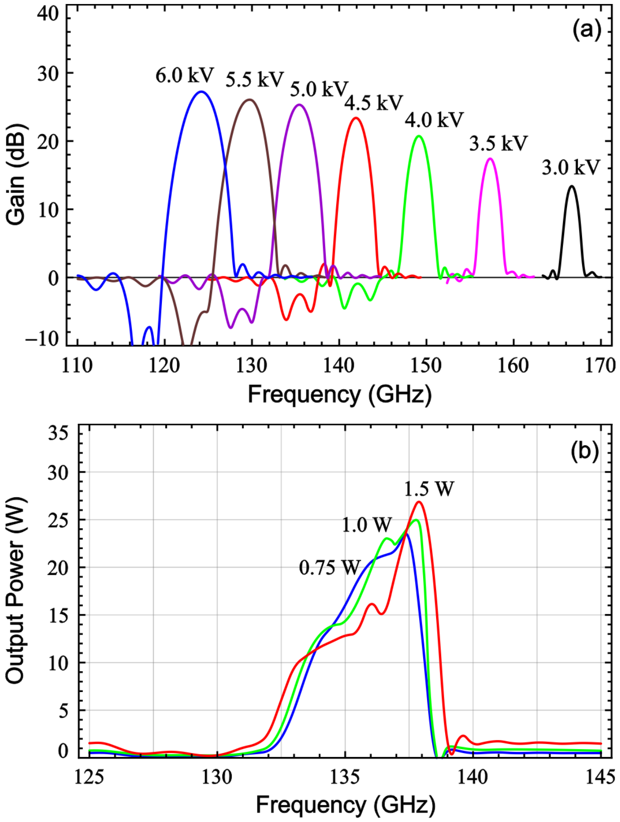

Figure 2. Small-signal gain versus frequency at different beam voltages (a) and output power versus frequency at 5.0-kV beam voltage and different driving powers (b).