Development of High-Power Sub-THz Traveling-Wave Tubes with Multiple Sheet Electron Beams

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Abstract— **We present the results of studies aimed at development of multiple-sheet-beam microfabricated traveling-wave tubes (TWT) at sub-THz frequency band. The double-tunnel TWT with a meander-line slow-wave structure (SWS) at V-band and the triple-beam TWT with grating SWS at G-band are designed. Technologies for microfabrication of the SWSs are discussed. The results of SWS fabrication and characterization are presented. Multiple-beam electron-optic system is designed and beam transportation in a uniform magnetic field is studied. The results of 3-D PIC calculation of small-signal and large-signal gain are presented.**

I. Introduction

Development of compact, high-power, wideband vacuum-tube sources of sub-THz and THz radiation is very important for many applications, especially for advanced telecommunication and radar systems. Using high-aspect-ratio sheet electron beams is helpful for reduce of the current density and increase of the output power. For the further increase of the power, it was suggested to develop devices with a spatially extended interaction space, which enables accommodation of multiple sheet beams [1]. Several designs of traveling-wave-tube (TWT) amplifiers have been proposed [2]-[8]. In this paper, we present the results of design and development of multiple-sheet-beam sub-THz TWT. Two designs are considered. The first one is the TWT with a multiple-tunnel meander-line SWS and vertically arranged sheet beams [7]. The second one is the TWT with horizontally arranged multiple elliptic beams interacting with a higher-order transverse mode of a dual-grating SWS [9].

II. Double-Tunnel Meander-Line SWS

The V-band TWT with a double-tunnel meander-line SWS was designed and simulated. A schematic diagram of the proposed structure is shown in Fig. 1. It consists of a meander-shaped metallic strip line affixed to two dielectric support plates inside a rectangular waveguide, which serves as a vacuum envelope. This arrangement of the support plates increases the thermal contact area and provides good heat dissipation capabilities. The TWT is driven by a 200-mA, 18-kV double sheet beam. According to 3-D particle-in-cell (PIC) simulation, over 250 W average output power and 25–30-dB small-signal gain can be attained with 1-2 W input power at 68 GHz [7].

For SWS microfabrication, we propose and verify a novel technology, which includes the following steps. At the first stage, a straight metallic strip with holes is fabricated by laser ablation from the copper foil of 50-um thickness. At the second stage, the fabricated strip is folded in the form of meander line so that the fabricated holes in the strip become tunnels for several electron beams. Several SWS samples consisting of 50 meander periods were fabricated. Dimensions of the microfabricated samples were studied by optical and scanning electron microscopy (SEM). In Fig. 2, a SEM image of a fabricated structure is presented. The preliminary analysis shows that the proposed approach is suitable for fabrication of such multiple-tunnel SWSs.

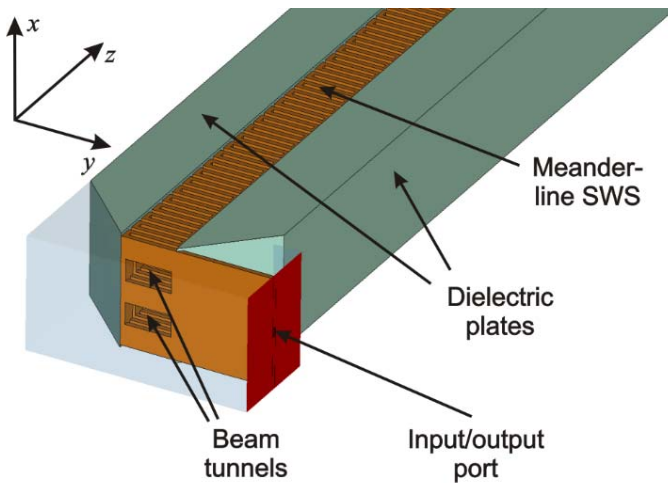

Fig. 1. Schematic of the double-tunnel meander-line SWS.

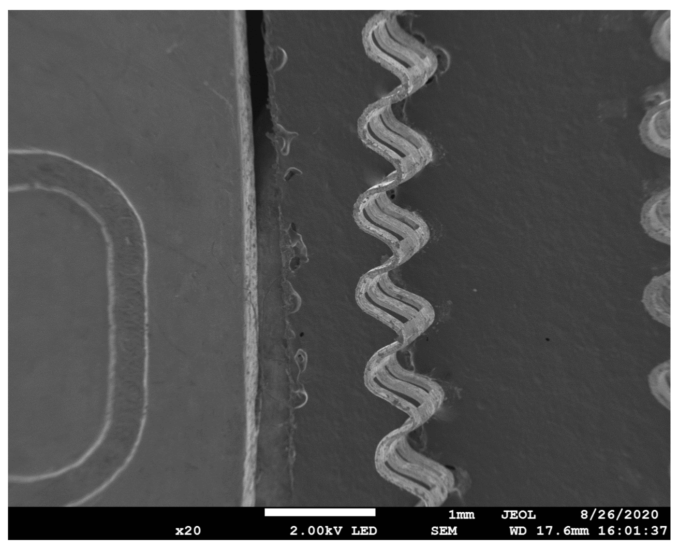

Fig. 2. SEM image of the double-tunnel meander structure.

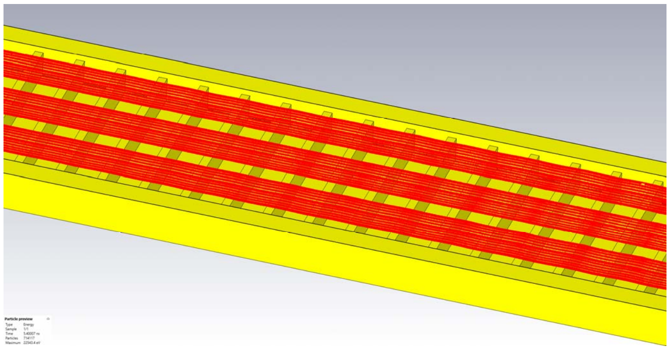

Fig. 3. Schematic of the TWT with triple sheet beam and grating SWS.

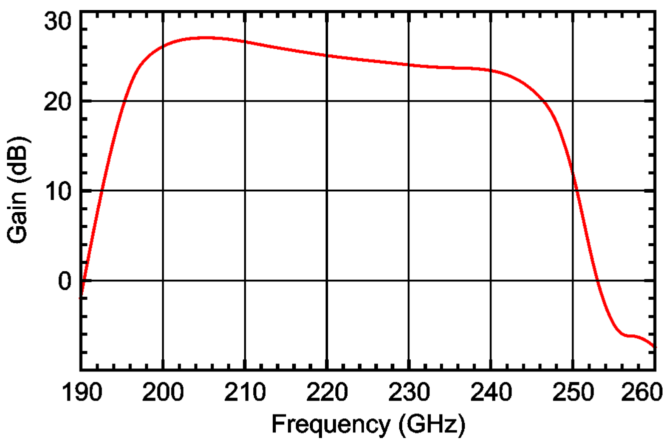

Fig. 4. Gain vs. frequency for 0.1-W input power.

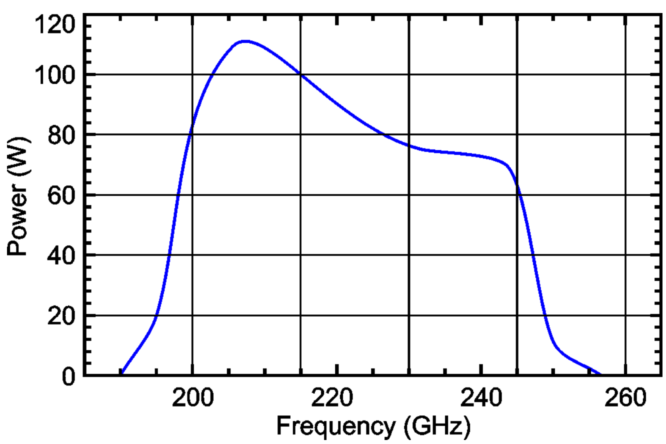

Fig. 5. Output power vs. frequency for 0.5-W input power.

III. TWT with a Triple Elliptic Beam and Dual-Grating SWS

TWTs with horizontally arranged multiple sheet electron beams interacting with a high-order TE_{n0} beam transverse modes have been proposed in several works [2]-[5]. We designed and studied a G-band TWT with triple elliptic electron beam and dual-grating staggered SWS [9]. Elliptic beams provide less deformation in a uniform magnetic focusing field than rectangular sheet beams. Schematic of the device is presented in Fig. 3. The beam interacts with a TE_{30} mode at frequencies around 220 GHz. Parasitic excitation of the backward-wave low-order TE_{10} and TE_{20} modes can be suppressed by using attenuating slabs located at positions where the field of the TE_{30} mode is zero [2]. We have studied several designs of the attenuator made from boron nitride or aluminum nitride. Performance of the TWT was investigated by 3-D PIC simulation. It was assumed that the SWS is driven by the 21.5-kV electron beam with 210-mA total current. Fig. 4 shows small-signal gain versus frequency. The gain exceeds 20 dB in a broad range of frequencies with maximal gain of 27 dB at 206 GHz. With 0.5-W input power the output power exceeds 110 W.

In addition, we have designed, simulated, and fabricated a triode electron gun generating three 300μm×600μm elliptic sheet beams [10]. The current of each beam was 31 mA, i.e. 93-mA total current was measured at 1100°C cathode temperature and 900-1000 V grid voltage. The permanent-magnet magnetic focusing system with 0.8-T magnetic field was also developed. The electron-optic system (EOS) containing a dispenser cathode, anode, collector, and magnetic system was fabricated and assembled. Beam propagation was simulated showing nearly 100% transmission at 40-mm distances.

IV. Acknowledgment

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