Traveling Wave Amplification from Multi-Beam Slow Wave Structures for High Power Millimeter and THz Wave Generation

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Abstract—In an effort to develop compact millimeter and THz wave radiation power sources, two types of traveling wave amplification concept with multi-beam have been studied using Pierce small signal analysis and particle-in-cell (PIC) simulation. Our prior work includes theoretical and numerical assessment on performance of the aluminum-nitride (AlN)-loaded multi-beam structure, indicating that the TM31-mode is amplified with 26 – 30 dB/beam at 64 – 84 GHz with three elliptical beams. Simultaneously suppressing lower order modes (TM11, TM21). The same analysis also shows that multi-staged cascading enables > 50 W of radiation power with 30 dB gain, which could be integrated on a single board substrate with multi-beam emitters by micro-fabrication. More schemes to improve device performance and to reduce physical sizes are continuously explored in advancing millimeter and sub-millimeter power radiation sources.

I. INTRODUCTION AND BACKGROUND

In an effort to develop compact millimeter and THz wave radiation power sources, the one-dimensionally polarized electron beam has been recently considered for THz wave source applications. Apparently, the radiation from the linear beam is appreciably more powerful when it is coherent. This, however, requires very high current density for the beam modulation in the THz regime. The high density of the charge bunches leads to growth of the beam emittance due to increasing space charge force, which can then cause abnormal beam-wave interaction. The beam would thus need to be immersed in a high magnetic field flux to compensate for the divergent defocusing force, thereby rendering the system bulky. Seeding a driving signal for the stimulated emission can significantly lower the current density threshold; THz band, however, lacks an available input driving source. Relevant to the issue, the multi-beam interaction concept has been considered to be a substantial solution to reducing charge density as well as to increasing radiation intensity [1]. It may nevertheless excite multiple modes, which could cause unstable overmoding problems, such as mode-competition/conversion and parasite oscillation. Among several higher-order-mode (HOM) filtering schemes [2, 3], dielectric implantation is distinctly advantageous for selecting a multi-beam interactive HOM. Embedding equally spaced lossy defects efficiently suppresses all other non-resonating modes, including trapped wakefields. Although this approach is feasible for achieving high power radiation by increasing the number of beams, its practical THz application is still challenging for related technical and physical issues.

This paper presents theoretical analysis and particle-in-cell (PIC) simulation results demonstrating millimeter and sub-millimeter wave radiations from overmoded and cascaded multi-beam traveling wave amplifiers. It will also discuss various approaches to mitigate intrinsic problems of multi-beam and sheet-beam slow wave structures capable of being applied to power THz sources through systematic assessment with theoretical analysis and computer modeling.

II. MULTI-BEAM TRAVELING WAVE AMPLIFICATIONS

The half-period staggering of a pair of 1-D vane arrays [4] results in a strong, symmetric axial electric field distribution of the fundamental mode along the direction of the electron beam propagation. For the simple simulation analysis, the slow wave structure is first designed with four dielectric plates (top and bottom) for TM11-mode. Our optimized dimensions give a mid-band frequency, corresponding to the TM31 mode. The > 10 kV beam line lies along the forward phase of the TM31 mode, indicating highest coupling between TM31 mode and the electron beam. Without the absorbers, transmission losses for all modes are approximately the same, 1 to 5 dB, corresponding to 0.5 ~ 2.5 dB/cm attenuation. With cascaded multi-beam TWT amplifiers that are designed to operate at the fundamental mode, an output signal from an amplifier is fed back to an input port of another one via a feedback waveguide coupler. The Pierce gain theory showed > 30 dB amplification. We examined the designed circuit (1st mode: staggered double grating array type), showing that the 80 mm long circuit has about 25 - 30 dB gain/beam, which is limited by the circuit efficiency. Since normally waveguide coupler in the frequency regime have about 0.02 – 0.04 dB/mm attenuation, about 6 – 7 circuits will be required to acquire 50 W output power (30 dB total gain), assuming the circuits have 7 dB gain. The circuit design optimization is underway.

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