21aE-7

Experimental Study of Intense Millimeter Wave Generation Based on Surface Wave Resonance Mode in Oversized Backward Wave Oscillator
大口径後進波発振器における表面波共振モードによる大強度ミリ波発生の実験的研究

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Intense millimeter wave generations by weakly relativistic oversized backward wave oscillators (BWOs) are investigated. There exists a starting energy for intense BWO oscillation to start, in addition to the well-known oscillation starting current. Above the starting energy, surface wave resonance mode is excited and BWO radiations increases drastically. We realize the intense BWO radiations in G-band as well as K- and Q-bands. Their figure of merit Pf^2 is about 3.5×10^2 [MW·GHz^2].

1. Introduction

Slow-wave high-power microwave devices such as backward wave oscillator (BWO) can be driven by an axially injected electron beam without initial perpendicular velocity and has been studied extensively as a candidate for high power microwave sources. In the slow-wave devices, a slow-wave structure (SWS) is used to reduce the phase velocity of electromagnetic wave to the beam velocity. To increase the power handling capability and the operating frequency, oversized SWSs with a diameter larger than free-space wavelength λ of output electromagnetic wave have been successfully used [1-3].

In order to sustain intense radiations of BWO with finite length SWS, there exist two threshold conditions on beam current and energy [4]. The former is well-known as an oscillation starting current. The latter is a starting energy for a resonance mode to form in a finite interaction space. For oversized BWO, this resonance mode is formed by the surface waves and is referred to surface wave resonance mode. If the surface wave resonance mode is excited above the starting energy, the radiation power drastically increases, by more than three-digit [5].

Table I. Parameters of oversize SWS

Band	D [mm]	z_0 [mm]	h [mm]	λ [mm]	D/λ
X	28.9	8.0	4.45	30	1.0
K	31.4	3.0	1.7	11.8	2.7
Q	30.0	2.0	1.0	7.5	4.0
G	30.0	0.5	0.3	1.7	18

In this work, oversized BWOs are driven by weakly relativistic electron beams less than 100 keV. Intense radiations from BWO based on the surface wave resonance mode are examined for a wide frequency range up to G-band.

2. Surface Wave Resonance Mode

We use sinusoidal and rectangular corrugations. Important parameters are amplitude h_0 and periodic length z_0. The corrugation wave number k_0 is defined as $k_0 = 2\pi/z_0$. Typical values of h_0 and z_0, as well as the SWS diameter of BWO at Niigata University are listed in Table 1. Values of D/λ are about 1 for the X-band and larger than 1 for the K- and Q-bands. Recently, the frequency of the surface wave increases up to G-band, for which D/λ becomes a very large value of about 18.

The radial boundary conditions at the corrugation wall connect the frequency f and the axial wave number k_z by the so-called dispersion relation. For SWS with a finite length of L, an axial boundary condition is added due to the reflection at the both ends and a resonance mode is formed. The beam interaction for such a resonance mode should satisfy the following axial condition [4, 5].

$$R_1 R_2 \exp\left\{-i\left(k_z^- - k_b\right)L\right\} = 1 \qquad (1)$$

Here, k_z^- and k_b are respectively the wave number of backward slow-wave and the beam mode, R_1 is the refraction coefficient at the beam entrance and R_2 is that at the other end. Equation (1) means that the field must be a single value at any axial position, after one round trip of the field. Two thresholds comes from the real and imaginary parts of eq.(1). The imaginary part determines the starting current. The real part is

$$\mathrm{Re}\left(k_z^- - k_b\right) = 2\pi N / L\,. \qquad (2)$$

Here, N is an integer corresponding to the spatial harmonic of the periodic system and N=-1 harmonic is dominant. In order to satisfy eq.(2), the interaction width Δk_z in the wave number space should be larger than $2\pi/L$.

In the oversized BWO, the surface waves form the surface wave resonance mode. The condition of eq.(2) cannot be satisfied by increasing only the beam current. By increasing the beam energy, the interaction point approaches the π point ($k_z z_0 = \pi$) and Δk_z increases. And Δk_z satisfies eq.(2) at the starting energy and intense radiations are realized based on the surface wave resonance mode [5, 6]. Note that the intense BWO operations are based on not based on the absolute instability, which never satisfy the axial boundary conditions.

4. Experimental Results

Tubular or disk cold cathodes proposed in Refs.[7, 8] are used. They can generate uniformly distributed annular beams with currents of hundreds of amperes in the weakly relativistic region. A beam limiter is placed to protect the corrugation surface. For beam prorogation, a uniform axial magnetic field B_0 is provided by 10 solenoid coils. The value of B_0 is about 0.8 T in this study. The radiated microwaves are picked up by rectangular horn antennas connected to waveguides.

We have studied weakly relativistic oversized BWOs in K- and Q-bands, using SWSs listed in Table I. They are driven by an annular electron beam with energy less than 100 keV. Radiation powers are up to about 500 kW and 200 kW for K- and Q-band BWO, respectively [3]. Figure of merit Pf^2 of our weakly relativistic BWO is about 3.5×10^2 [MW・GHz^2]. And it is almost the same as previous weakly relativistic X-band BWO. Recently, our intense radiations of oversized BWO has been extended up to the G-band using SWS listed in Table I [4]. The maximum power level is estimated to be above 10 kW level. The figure of merit is in the same level as the lower frequency BWOs in X-, K- and Q-band.

5. Summary

Oversized BWOs are driven by weakly relativistic electron beams less than 100 keV. Intense radiations from oversized BWOs are based on the surface wave resonance mode, not on the absolute instability. For the surface wave resonance mode operations of BWO, the starting energy as well as the starting current should be satisfied. And we demonstrate the intense BWO operations up to G-band. The figure of merit of our oversized BWO is $Pf^2 = 3.5\times10^5$ [kW・GHz^2] in the wide frequency range including terahertz BWO and non-oversized X-band BWO.

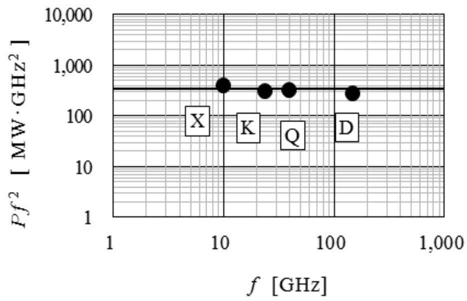

Fig. 1. Figure of merit of weakly relativistic BWO

Acknowledgments

This work was partially supported by Grant-in-Aid for Scientific Research (B) No. 23340173 from the Japan Society for the Promotion of Science and by the NIFS collaboration research program No.NIFS14KLER031.

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