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Article / Book Information

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Title(English)	Study on High Output Power Resonant-Tunneling-Diode Terahertz Oscillator with Cavity Resonator
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Category(English)	Doctoral Thesis
種別(和文)	論文要旨
Type(English)	Summary

（博士課程）
Doctoral Program

論 文 要 旨

THESIS SUMMARY

系・コース： Department of, Graduate major in	電気電子 電気電子	系 コース	申請学位（専攻分野）： Academic Degree Requested	博士 Doctor of	（ 学術 ）
学生氏名： Student's Name	Han Feifan		審査員主査： Chief Examiner	鈴木左文	

要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

In this thesis, high output power resonant-tunneling-diode (RTD) terahertz oscillators with cavity resonator were investigated with seven chapters.

Chapter 1 introduces the fundamental properties of terahertz (THz) waves. THz applications including spectroscopy, THz imaging and wireless communication are briefly reviewed. Among the introduced candidates for THz sources, RTD oscillators have shown potential to achieve high output power in array configuration. Then the significance of array size in practical applications was discussed, which led to the consideration of power density. Power density, defined as the ratio of output power to device intrinsic area, was analyzed with wireless communication applications. The future device in wireless communication is proposed with a concept of large RTD oscillator array controlled by complementary metal-oxide-semiconductor (CMOS) external circuits for power combination. To this end, objectives of this thesis which includes the focus on increasing the output power of a single RTD oscillator, thereby enhancing power density in THz systems is indicated.

Chapter 2 theoretically explains the methods for high output power and presents the demonstration of cavity resonator. A conventional RTD oscillator was first analyzed to propose high output power methods using low-loss resonator, high current density RTD, impedance matching of radiation conductance, and coupling of two RTDs in one oscillator. Then, a cavity resonator with low conduction loss was introduced following with an analysis using equivalent circuit model and three-dimensional electromagnetic simulations. The device was successfully fabricated by a fabrication process utilizing multi-layer resist patterning. The cavity resonator was demonstrated with a high output power of 0.13 mW at 730 GHz. Finally, a discussion on the difference between experiment and theory implied the heat destruction problem and series resistance problem.

Chapter 3 presents the improvements for RTD layers. It first provides a theoretical discussion of thermal characteristics of RTD. A three-dimensional thermal analysis model was constructed, and the device structure with thermal circuit was clarified. By replacing the low thermal conductive n^+-InGaAs layer with high thermal conductive n^+-InP, the junction temperature of RTD could be decreased by ~100 K. The largest RTD area without heat destruction in experiment raised from 6 to 11 μm^2 which confirmed the effect of introduced n^+-InP layer. With this heat dissipation structure, thin barrier RTDs were introduced, and high current density up to 26.4 and 40 mA/μm^2 were achieved with 0.9 and 0.8 nm barriers, respectively. Moreover, for reduction in series resistance, 40 nm n^+-InGaAs was inserted above the n^+-InP conductive layer for Ohmic contact of lower electrode, and the distance between electrodes was reduced.

The series resistance drops from 1.67 to 0.25 Ω.

Chapter 4 investigates an array configuration for coherent power combination based on cavity resonator. A structure of two RTDs integrated into one same cavity and connected to a shunt resistor for coherent mutual coupling is proposed. The output power is increased by power combining while the resonator area remains, and power density is thus improved. Two RTDs are considered to work in anti-phase operation to cancel the electric field at the shunt resistor located at the midpoint between RTDs for low conduction loss. Utilizing this operation mode, two RTDs fed to ring slot antenna are in phase for efficient radiation. The admittance matrix analysis was performed with equivalent circuit model and three-dimensional electromagnetic simulations to confirm the anti-phase operation. In device fabrication, lower electrode deposition with self-alignment was introduced in addition to the fabrication process used in chapter 2. A single peak of the frequency spectrum proved the coherent operation of two RTDs. A high output power of 0.24 mW and power density of 95 mW/mm^2 at 925 GHz were achieved with cavity length of 24 µm, width of 4 µm, height of 2 µm, and ring radius of 20 µm. The results showed the improvement of power density with cavity resonator coupled with two RTDs.

Chapter 5 describes the theory of impedance matching method in RTD oscillators for high output power. It first analyzed numerically with the equivalent circuit model of cavity type coupled resonator in chapter 4. From calculation, the maximum power was extracted from RTD when radiation conductance G_{rad} is half of the difference between RTD conductance G_{RTD} and conduction loss G_{loss}. The method of controlling G_{rad} by changing the size of ring slot antenna for impedance matching condition was proposed. The increase of output power at low frequency using large ring slot antenna in experiment indicated the impedance matching effect. Increasing cavity length to integrate large RTDs for high output power was also proposed.

In chapter 6, high current density RTDs, coupled structure with long cavity and impedance matched antenna are combined to achieve higher power density. A metal-insulator-metal capacitor integrated at the center of the cavity is introduced for stable anti-phase mode operation. With all those methods, power densities of the device reached to 290 and 160 mW/mm^2 at 740 and 1000 GHz, respectively.

Finally, chapter 7 gives the conclusions of this study.