【Grant-in-Aid for Scientific Research (S)】

Breaking the operational limit of electronic device by revealing its hidden wave nature

Principal Investigator	Tokyo Institute of Technology, School of Engineering, Associate Professor SUZUKI Safumi Researcher Number : 40550471
Project Information	Project Number : 24H00031 Project Period (FY) : 2024-2028 Keywords : Terahertz, Resonant tunneling diodes, Metamaterial, Photonics

Purpose and Background of the Research

●Outline of the Research

The terahertz (THz) wave with a frequency range of 0.1 to 10 THz falls between radio waves and lights. Researches on THz signal sources have been conducted using electronic devices at lower frequencies and optical devices at higher frequencies. However, generating high-power THz signals remains challenging due to the physical limitations of both types of devices. Resonant tunnel diodes (RTDs) have THz gain due to negative resistance characteristics and have achieved 2 THz oscillations, thus entering the range of optical devices. Furthermore, RTDs potentially have a wave nature similar to that of photonic devices.

Therefore, in this project, we will elucidate the wave nature inherent in RTDs and develop unique active metamaterials that enhance the interaction with electromagnetic waves. Through this project, we aim to surpass the operational limits of conventional electronic devices.

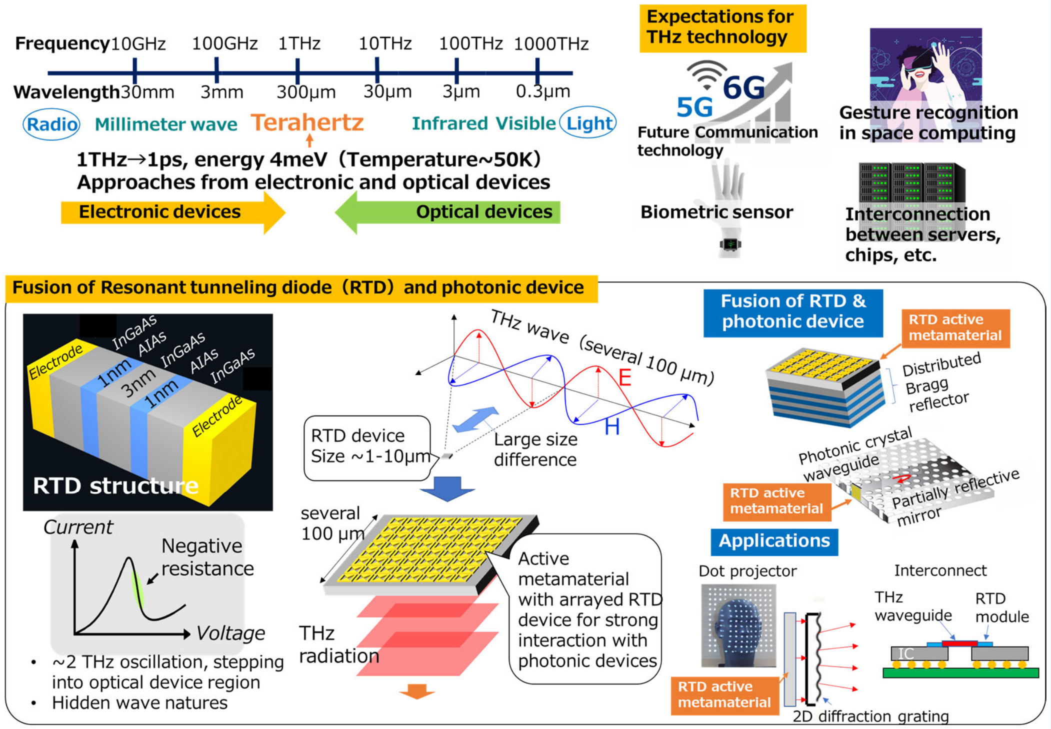

Figure 1. Overall image of the research

Expected Research Achievements

●Development of RTD active metamaterial

The interaction between RTDs and THz waves is small due to the significant size difference. Therefore, as shown in the bottom center of Figure 1, an active RTD metamaterial is formed using an array configuration in which RTDs are arranged in a plane, which enables strong coupling with THz waves and photonic devices.

●Fusion of RTD active metamaterials with photonic devices

We aim to develop novel device operations by combining the developed RTD metamaterial and various photonic devices. A distributed Bragg reflector (DBR) is a photonic device that uses standing waves to reflect only specific frequencies and functions as a low-loss resonator. By combining the DBR with RTD metamaterials, we aim to develop a new signal amplification mechanism similar to that of optical devices. This mechanism has the potential of achieving a significant frequency increase of >3 THz, a feat not yet achieved by conventional electronic devices (Figure 2).

A photonic crystal serves as a low-loss THz waveguide with various functionalities. By combining the RTD metamaterial and photonic crystal waveguide, the feedback to the RTD can be highly controlled by placing an arbitrary reflector in the waveguide, ultimately resulting in high-speed direct modulation.

Recently, the phenomenon of amplified detection was discovered in RTDs, which enabled high-sensitivity THz detection. Our aim is to determine whether this amplified detection can be explained by conventional models of electronic and photonic devices. Alternatively, we seek to explore whether it operates based on a new principle.

●New THz applications

We also aim to demonstrate new THz applications using the developed RTD devices. THz interconnect, which connects semiconductor chips at short distances of several tens of centimeters using THz waves propagating in dielectric materials, is attracting attention as a new technology with high capacity and low power consumption compared to electric wiring (Figure 3). We will demonstrate THz interconnect by connecting RTD transmitters and receivers.

THz dot projectors could facilitate easy measurement of the 3D shapes of hidden objects using the transparency of THz waves. We will create a THz dot projector that combines the RTD metamaterial and 2D diffraction grating and take on the challenge of shape measurement.

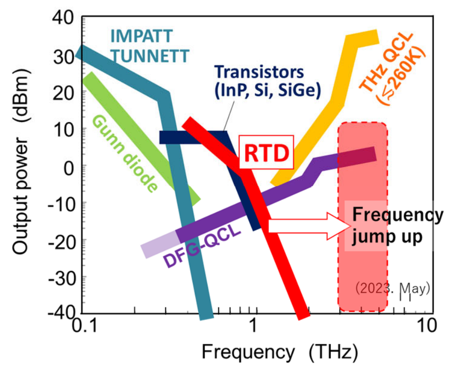

Figure 2. Current status of THz signal sources.

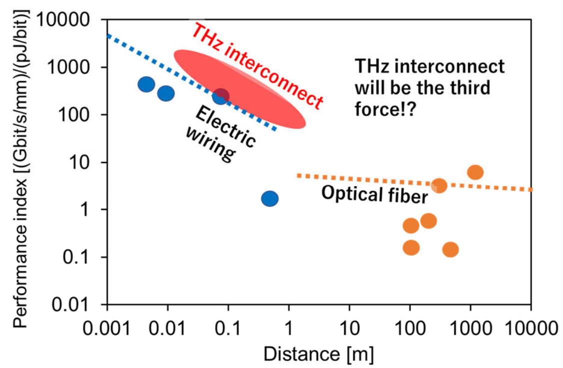

Figure 3. Expected performance of THz interconnect.

Homepage Address, etc.	http://www.pe.titech.ac.jp/SuzukiLab/index.html