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2022
Development of terahertz device using resonant tunnel diode (RTD) (Canon)

~ Discrete Semiconductor/Others ~

Electromagnetic waves with frequencies of 0.1 to 10 THz (spatial wavelengths of 3 mm to 30 μm) are called terahertz waves.

Terahertz waves have been only used for radio telescopes and human body scans. Their wide use has been remained unexplored because of their location at the boundary between radio waves and light waves, and the technical difficulties in its generation and detection. In recent years, it has been spotlighted that advances of technology have made it possible to use terahertz-band electromagnetic waves for new imaging, inspection, and high-capacity communications. In the telecommunications field, the radio bandwidth is going to expand to terahertz waves in the 6th generation mobile communication system (6G). The fifth-generation mobile communication system (5G), which began commercial operation in March 2020, extended the radio bandwidth to tens of GHz and enabled wireless communications at a communication speed of 10 Gbps. In 6G, which is targeted for commercialization in the 2030s, the use of terahertz waves is planned to realize 100 Gbps high-speed wireless communications. Although limited to indoor or short-range local area wireless communications due to its straight traveling property and high attenuation caused by absorption of water vapor, terahertz wave communications are considered a strong candidate for achieving ultra-high data rates at access points in Beyond 5G/6G networks [(1)].

Optical devices such as quantum cascade lasers and electronic devices such as IMPATT diode frequency multipliers have been commercialized as terahertz wave sources. However, they tend to be large equipment. In contrast, the resonant tunneling diode (RTD) has attracted attention because it is a discrete semiconductor device that operates at room temperature and it can generate terahertz-wave fundamental oscillation.

Figure 1 shows an example of the structure of a resonant tunneling diode (RTD), and its potential distribution of conduction band electrons is shown in Figure 2 [(2)]. The main part of the RTD consists of a quantum well layer (InGaAs) sandwiched between barrier layers (AlAs) on both sides, and the conduction of electrons takes place through the resonance levels of the quantum well [(3)]. Therefore, when the conduction band bottom of the step emitter (InAlGaAs) is higher than the resonance level, the current decreases with increasing voltage and a negative resistance is appeared from the point of view of the current-voltage characteristic as shown in Figure 3, which enables oscillating operation [(4)].

Canon proposed an oscillating device that combined an RTD and a patch antenna that emitted terahertz wave perpendicular to the antenna surface (5), which expanded this technological concept to the development of the terahertz oscillation device as shown in Figure 4 (6) (7).

The heart of the RTD chip consisted of a monolithic integration of 6 x 6 (36) patch antenna arrays.

InGaAs-InAlAs double-barrier RTDs grown on an InP substrate were used in the device. The bottom electrode layer of the RTD was used as a ground plane, and the patch antenna, microstrip lines, etc. were integrated on the InP substrate. The length of one side of the patch antenna was set to 1/2 of the effective wavelength (170 μm). The two RTDs were arranged in mirror symmetry with respect to the center of the patch antenna and operated in push-pull mode, adapting to the so-called double-resonant-tunneling-diode patch-antenna structure (8).

In a patch antenna array, the antennas were arranged at a pitch of 400 μm. Each patch antenna was connected by a microstrip line with a length of one effective wavelength in the X direction (perpendicular to the resonance direction of the patch antenna) and 1/2 the effective wavelength in the Y direction (parallel to the resonance direction of the patch antenna). This resulted in coherent oscillations with synchronized 72 RTDs in the antenna array, since all patch antennas were synchronized in the same mode. In this configuration, terahertz waves with an output of 11.8 mW at a frequency of 0.45 THz was radiated perpendicular to the antenna surface, and coherent oscillation provided a radiation intensity of 210 mW/sr and higher directivity with a 3 dB beam width of 13 degrees.

It was confirmed that the oscillation frequency was tunable with structural adjustments. It was demonstrated that the RTD oscillator was able to oscillate in the 10 mW range of output power which was previously limited within the μW range. It was shown that these devices were promising as practical terahertz sources not only for terahertz imaging, but also for radar sensing and future 6G communications.

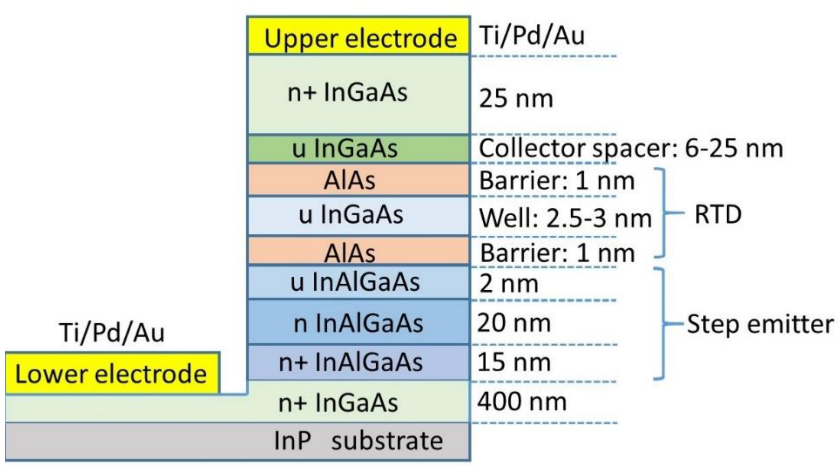

Figure 1 Cross-sectional structure of a resonant tunnel diode (RTD) (2)

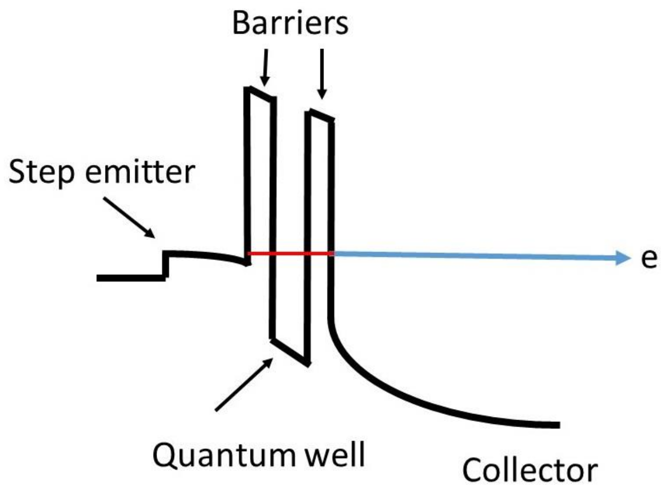

Figure 2 RTD band structure (2)

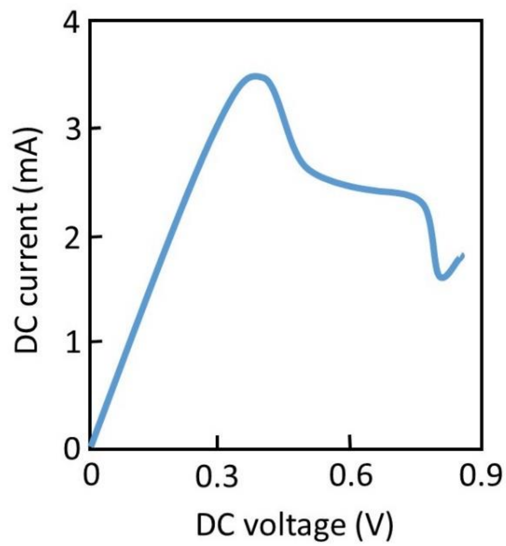

Figure 3 I-V characteristics of RTD (2)

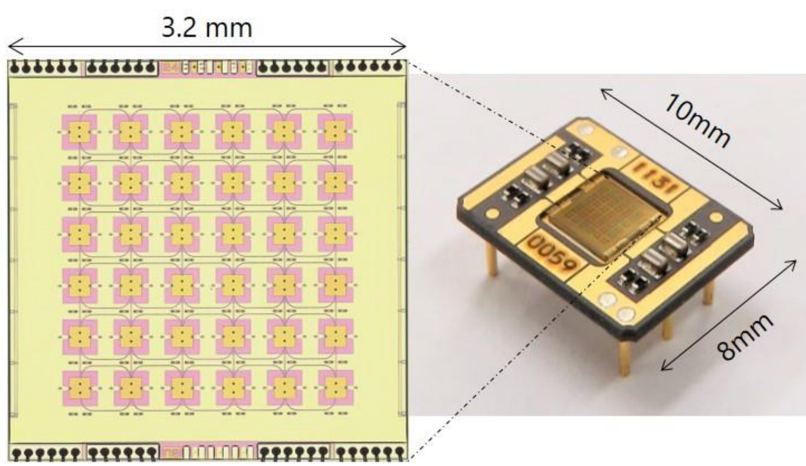

Figure 4 RTD-based THz source (0.45 THz, 6×6 array) (6) (7)
(Courtesy of Canon Inc.)

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