Antenna-Coupled GaAs SBD Detectors for 100 GHz Band Radiation

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***Abstract*—Thin-film slot antenna coupled GaAs Schottky barrier diodes (SBDs) were fabricated using a micro-fabrication technique, and detection properties such as antenna pattern, video detection and mixing were investigated at 100 GHz band. The E-plane and H-plane antenna patterns agreed well with the theoretical values and the operation of one-wavelength antenna was confirmed. The fabricated device had a noise equivalent irradiance (NEI) of about 2.0×10^{-8} W/cm^{2}Hz$^{1/2}$. The IF signals were observed up to the harmonic number of 7.**

I. Introduction

RECENTLY, the terahertz (THz) waves, which lies in the frequency region between 100 GHz and 10 THz, have been attracting significant attention for applications such as communications, imaging, medical diagnostics, health monitoring, agriculture, and so on [1]. So far, a THz time-domain spectroscopy (THz-TDS) has been used for these applications. However, it is important to develop the THz radiation sources and detectors to promote the THz wave applications further. We have been studying the antenna-coupled devices [2, 3] toward the development of THz wave detectors operated at a room temperature with a high sensitivity. A GaAs Schottky barrier diode (SBD) is one of the most utilized detectors in heterodyne receivers and so on in the THz frequency range [4]. In the present study, we fabricated slot antenna coupled GaAs SBD detectors, and investigated the detection properties such as antenna pattern, video detection and harmonic mixing at 100 GHz band.

II. Experimental Results And Discussion

Figure 1 shows the SEM photograph of the fabricated slot antenna coupled GaAs SBD detector for 94 GHz radiation. The antenna has a structure with a rectangular hole and Au ground plane. The length and the width of the antenna were selected to be 870 μm and 97 μm, respectively, so that the antenna operates as one-wavelength antenna for 94 GHz [5]. A GaAs SBD was fabricated using n-GaAs layers grown on a S.I. GaAs substrate. An electron beam evaporated Ti/Pt/Au Schottky contacts with a diameter of 2 μm and Au/Ge/Ni/Au ohmic contact layers were formed on n-GaAs, respectively. The SBD was placed at the center of the antenna. The slit lines are DC cuts for applying DC bias current to the SBD.

In the video detection, the 94 GHz signal wave was electrically modulated at 1-5 kHz and the modulated signal was irradiated to the device through a horn antenna. The detected voltage was measured by a lock-in amplifier.

The E-plane and H-plane antenna patterns were measured at 94GHz. The device was placed on a rotating stage. The detected voltage was measured with changing the angle of the incidence. Figure 2 shows the E-plane and H-plane antenna patterns when the 94 GHz electromagnetic wave was irradiated through the GaAs substrate. In the figures, the solid squares and the solid lines denote the experimental and theoretical patterns, respectively. The experimental patterns agree well with the

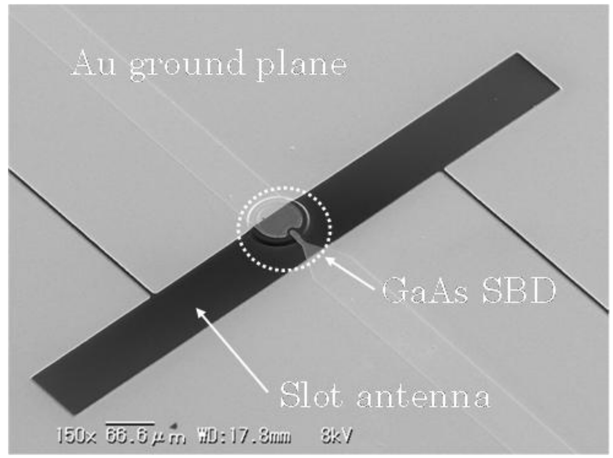

Fig. 1 SEM photograph of the fabricated GaAs SBD coupled with a slot antenna for 94 GHz radiation

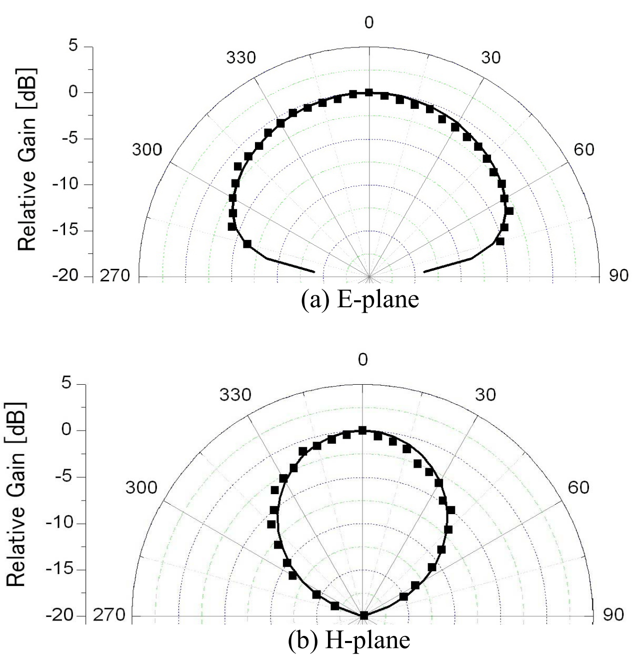

Fig. 2 E-plane (a) and H-plane (b) antenna patterns of the single slot antenna through the GaAs substrate

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theoretical patterns derived from the theory based on the transmission line model [6]. The E-plane and H-plane antenna patterns when the 94 GHz wave was irradiated from the air-side also agreed well with the theoretical patterns. From these experimental results, it was confirmed that the slot antenna

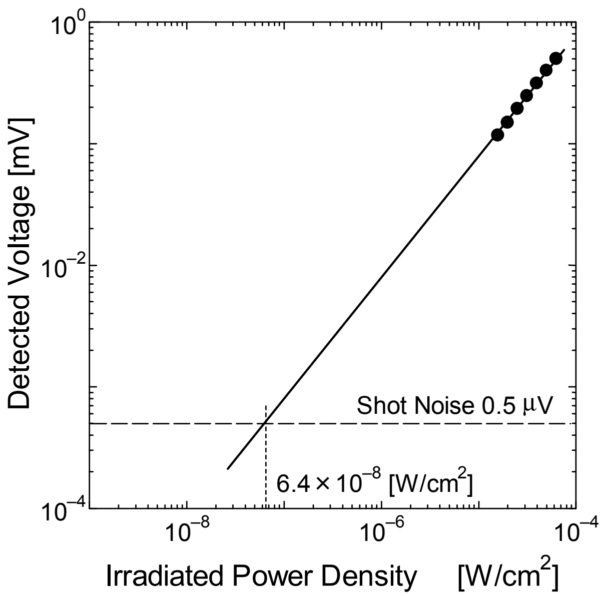

Fig. 3 Irradiated power density dependence of detected voltage at 94 GHz

operated as one-wavelength antenna.

The bias voltage dependence of the detected voltage was measured at 94GHz to investigate a detection mechanism of the device. The detected voltage and calculated value derived from the theory of square-law detection showed almost the same variation along the bias voltage, and became maximum at the bias voltage of about 0.6V. This result indicates that the detected voltage is obtained by the non-linearity of current-voltage characteristic of the device.

Next, we evaluated a noise equivalent irradiance (NEI). From the measurement of a noise characteristic, it was found that a 1/f noise was dominant up to noise frequencies of about 4 kHz and a shot noise became dominant at the frequencies over 4 kHz. Under the optimized bias condition of about 0.6 V, the voltage due to the shot noise was about 0.5 μV and constant over 4 kHz. The bandwidth Δf was 10 Hz. Figure 3 shows the irradiated power density dependence of detected voltage at 94 GHz. The solid circles denote experimental values and solid line is a guide line for experimental values. The detected voltages were proportional to irradiated power density. The value of NEI obtained from the voltage of the shot noise (0.5 μV) was about 2.0×10^{-8} W/cm^{2}Hz$^{1/2}$.

In the harmonic mixing, the 94 GHz signal and the 13.414 ~ 93.9 GHz LO waves were simultaneously irradiated to the device through the horn antennas. An IF signal was measured by a spectrum analyzer. The LO power dependencies of IF signal intensity were shown in Fig. 4. In this experiment, the IF signals of 100 MHz were observed up to the harmonic number of 7. The IF output increased in proportion to signal intensity. However, as can be seen from the figure, the change of the IF output with the LO wave intensity strongly depended on a harmonic number as expected from the mixing theory. From this experimental result, it was found that the device had the non-linearity up to 7th order at least.

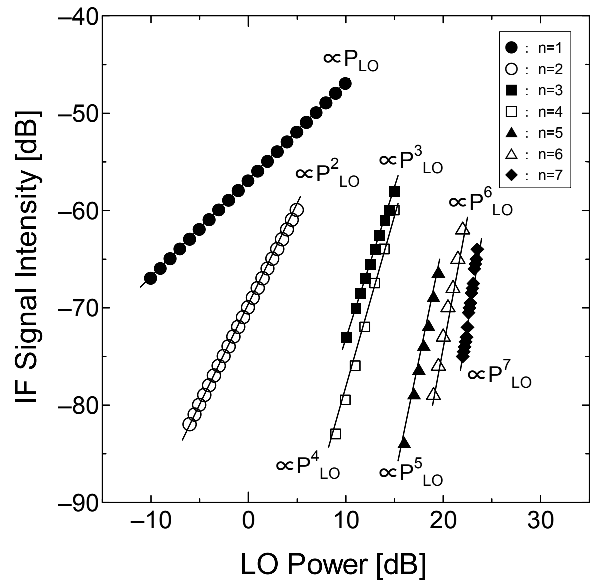

Fig. 4 LO power dependencies of IF signal intensity

III. CONCLUSIONS

We fabricated the slot antenna coupled GaAs SBDs and investigated the detection properties such as video detection and mixing at 94 GHz. In the video detection, the NEI of about 2.0×10^{-8} W/cm^{2}Hz$^{1/2}$ was obtained. The IF signals were observed up to the harmonic number of 7. A higher sensitivity can be expected by introducing an array antenna structure and coupling with an extended hemispherical lens.

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