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EVALUATION OF FAR-INFRARED BIB-TYPE GE DETECTORS FABRICATED WITH THE SURFACE-ACTIVATED WAFER BONDING TECHNOLOGY

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ABSTRACT

To realize large-format compact array detectors covering a wide far-infrared wavelength range up to 200 μm, we have been developing Blocked-Impurity-Band (BIB) type Ge detectors with the room-temperature surface-activated wafer bonding technology provided by Mitsubishi Heavy Industries. We fabricated various types of p^+-i junction devices which possessed a BIB-type structure, and evaluated their spectral response curves using a Fourier transform spectrometer. From the Hall effect measurement, we also obtained the physical characteristics of the p^+ layers which constituted the p^+-i junction devices. The overall result of our measurement shows that the p^+-i junction devices have a promising applicability as a new far-infrared detector to cover a wavelength range of 100–200 μm.

Key words: instruments: far-infrared detector

1. INTRODUCTION

In order to cover far-infrared (IR) wavelengths longer than 100 μm, stressed Ge:Ga detectors with the Ga concentration of $\sim 10^{14}$ cm^{-3} were onboard the Spitzer, Herschel and AKARI satellites. However, it is difficult to realize large-format compact array detectors, because these detectors need a huge mechanical system to stress the detectors. We have been developing Blocked-Impurity-Band (BIB; Petroff et al. 1986) type Ge detectors which can cover a wide far-IR wavelength range up to 200 μm without a huge mechanical system (Watanabe et al. 2011; Kaneda et al. 2011; Suzuki et al. 2012). They are expected to realize large-format compact array detectors. The detectors consist of a heavily-doped Ge:Ga (p^+ layer) for detecting far-IR photons and a non-doped intrinsic Ge (i layer) for blocking dark current. We fabricated BIB-type Ge detectors with clean abrupt junctions using the room-temperature surface-activated wafer bonding technology provided by Mitsubishi Heavy Industries (Takagi et al. 1996; Takagi & Maeda 2006).

2. MEASUREMENTS

We measured spectral and absolute responsivity for various types of Ge:Ga devices. We fabricated three devices; a bulk device with a Ga concentration of 2×10^{14} cm^{-3}, a p^+-i device consisting of a p^+ layer with a Ga concentration of 1×10^{16} cm^{-3} and an i layer with 0.5 mm thickness for both, and a thinned device consisting of the same structure of the p^+-i device except for an i layer thickness of 0.05 mm. The sizes of the former two devices are $1\times1\times1$ mm^3, while the size of the thinned device is $1\times1\times0.55$ mm^3. We obtained the spectral response curve of each device by a Fourier transform IR

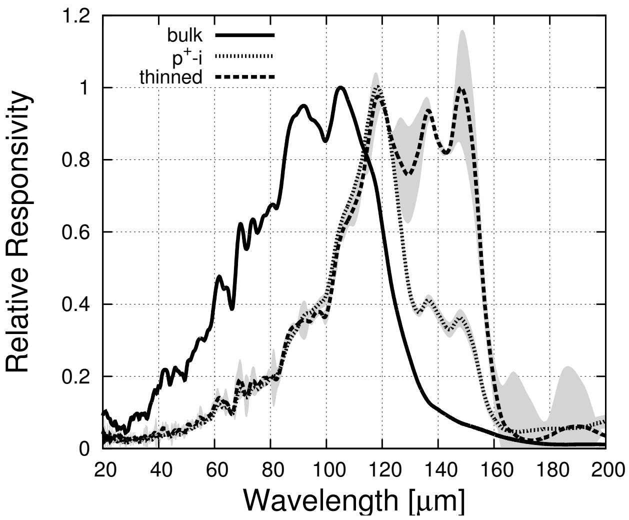

Figure 1. Spectral response curves for the three devices. The vertical axis shows the relative responsivity where the peak is normalized to a unity for each device. The hatched regions represent 1σ errors.

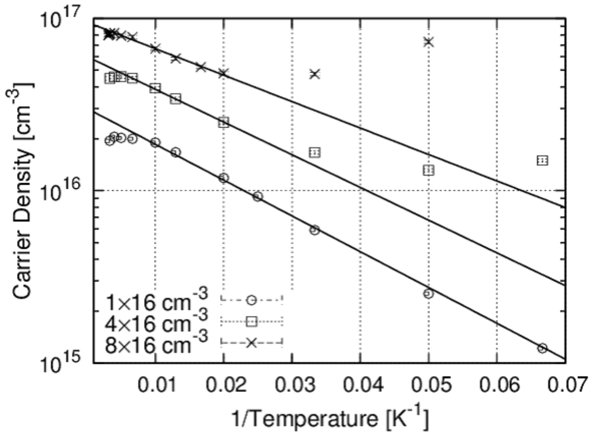

Figure 2. Carrier densities as a function of temperature.

Table 1
Parameters for the measurements and the result.

	Spectral responsivity		Absolute responsivity	
Devices	Temperature	Bias	Bias field	Result
bulk	2.8 K	25 mV	300 V/m	4.5 ± 0.9 A/W
p^+-i	2.8 K	1.5 V	2000 V/m	2.8 ± 0.3 A/W
thinned	3.4 K	600 mV	2000 V/m	13 ± 1 A/W

Table 2
Results of the Hall effect measurement.

Samples	E_A	Cut-off wavelength
$1{\times}10^{16}$ cm^{-3}	7.3 ± 0.1 meV	168 ± 2 μm
$4{\times}10^{16}$ cm^{-3}	6.8 ± 0.1 meV	181 ± 3 μm
$8{\times}10^{16}$ cm^{-3}	5.9 ± 0.1 meV	209 ± 4 μm

spectrometer. We also measured the absolute responsivity of the three devices under low-background conditions by a blackbody source.

In order to obtain the physical characteristics of the p^+ layers, we also evaluated the temperature dependence of the carrier density using the Hall effect. We used three Ge:Ga samples with the Ga concentrations of $1{\times}10^{16}$, $4{\times}10^{16}$ and $8{\times}10^{16}$ cm^{-3}. The relation between the carrier density, p, and the depth of the Ga energy level, E_A, is $p \propto \exp(-E_A/2k_BT)$, where k_B is the Boltzmann constant and T is the temperature. We calculated E_A by using this equation and estimated the cut-off wavelength from E_A.

3. RESULTS & DISCUSSIONS

Figure 1 shows the spectral response curves of the devices. Operating temperatures and bias voltages for the devices are summarized in Table 1. The cut-off wavelengths of the bulk, the p^+-i and the thinned devices are estimated to be 122 ± 5, 140 ± 10 and 155 ± 3 μm, respectively, from 30–70 % levels of the peak responsivity. This result demonstrates that the BIB-type devices have cut-off wavelengths longer than the bulk Ge:Ga device. Table 1 also shows the absolute responsivity of the devices with the bias fields applied to the effective detection regions. Combined with the spectral response curve in Figure 1, the result shows that the thinned p^+-i device has a higher absolute responsivity at wavelengths 130–160 μm than the non-thinned p^+-i device, which is probably caused by increase in the effective bias applied to the p^+ layer because of thinning the i layer.

The Hall effect measurement was performed at temperatures of 15–300 K. The result is shown in Figure 2. We estimated E_A using the data points at 0.01–0.07 K^{-1} for the 1×10^{16} cm^{-3} sample. For the other samples, we could not use the data points at 0.03–0.07 K^{-1}, because the hopping current contributed much to the carrier densities. The derived E_A and corresponding cut-off wavelengths are summarized in Table 2. The cut-off wavelengths derived from this measurement roughly agree with those of the BIB-type devices from the spectral responsivity measurement. Our result indicates that the Ga concentration of the p^+ layer should be $8{\times}10^{16}$ cm^{-3} in order to extend the cut-off wavelength up to 200 μm.

4. SUMMARY

We performed the spectral and absolute responsivity measurements of three devices and the Hall effect measurement of three samples. From the result, we find that the BIB-type devices have cut-off wavelengths of 130–160 μm, which are significantly longer than that of a conventional bulk Ge:Ga device. We estimate that the Ga concentration of a p^+ layer is 8×10^{16} cm^{-3} to cover wavelengths up to 200 μm. The overall result of our measurement demonstrates that the p^+-i junction devices have a promising applicability as a new far-IR detector to cover a wavelength range of 100–200 μm.

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