*Digest of Tech. Papers* *The 9th Conf. on Solid State Devices, Tokyo*

# C—2—3 400 GHz Band Operation of Cooled Silicon IMPATT Diodes

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Recently, oscillation frequency of IMPATT diodes has been increased to near 400 GHz.[1] In high frequency region, several effects such as the ionization rate saturation, carrier diffusion, series resistance, velocity modulation, etc. reduces oscillation performance of IMPATT diodes. However, a larger current density and the increase of carrier saturated velocity and ionization rate will improve the diode characteristics. So, liquid nitrogen cooled silicon IMPATT diodes were examined on a viewpoint of high frequency performance.

Fig.1 shows the calcurated small signal diode admittance of $p^+nn^+$ SDR ($n=4.5\times10^{17}$ /cm$^3$ ) for operation temperature, T=330°C and T=20°C at current density, $J_{dc}=8.0\times10^4$ A/cm$^2$. The temperature dependence of carrier saturated velocity[2] and ionization rate,[3] and ionization dead space ( Threshold energy,[4] $E_e$=1.8 eV for electron and $E_h$=2.4 eV for hole ) were considered. With increasing the temperature, the decrease of negative conductance particularly in high frequency region and the shift of optimum frequency to lower one are found. The frequency shift are caused mainly due to the saturated velocity decrease. The decrease of the negative conductance reduces a diode transfer efficiency too.

Tested diodes were $p^+nn^+$ structure SDRs of depletion layer width about 0.15 $\mu$m at breakdown voltage (room temp.). Diode parameters are listed in Table 1. The $p^+$ layer was formed by boron diffusion at 900°C, for 4 min., and n layer was formed by $^{31}P$ ion implantation of two acceleration energies, to get uniform donor density.

The diode was mounted in full height R-2200 (1.092×0.546 mm$^2$ ) waveguide cavity with an adjustable short, and diode mount was contacted with liquid nitrogen vessel in vacuum. An output power was measured by thin film thermo-couple (300 GHz band ) or W-pSi point contact diode (400 GHz band).

At 412 GHz, an output power of 2.2 mW with conversion efficiency 0.047 % and at 295 GHz, 4.5 mW with 0.13 % were obtained. (Fig.2) At 412 GHz operation, the diode was biased in voltage and current, 9.33 V and $1.2\times10^5$ A/cm$^2$, respectively. The junction temperature was estimated to be about 250°C. The highest frequency of 430 GHz was observed with output power of several $\mu$W.

1) M.Ino, T.Ishibashi and M.Ohmori, Proc. of 8th Conf. on Solid State Devices, J.J.A.P, Vol.16, Suppl., 16-1, p.89

2) D.R.Decker and C.N.Dunn, J.Electronic Materials, Vol.4, No.3, p.527(1975)

3) W.N.Grant, Solid State Electronics, Vol.16, p.1189 (1973)

4) J.C.Moll and R.Van Overstraeten, Solid State Electronics, Vol.6, p.147 (1963)

Table.1 Diode parameters

| | J-2 | J-3 |
|---|---|---|
| n layer carrier density | $4.5\times10^{17}$ | $5.0\times10^{17}$ (/cm$^3$) |
| breakdown voltage, room temp. | 7.9 | 7.4 (V) |
| ( 〃 ) 77K | 7.2 | 6.8 (V) |
| depletion layer width | 0.15 | 0.14 ($\mu$m) |

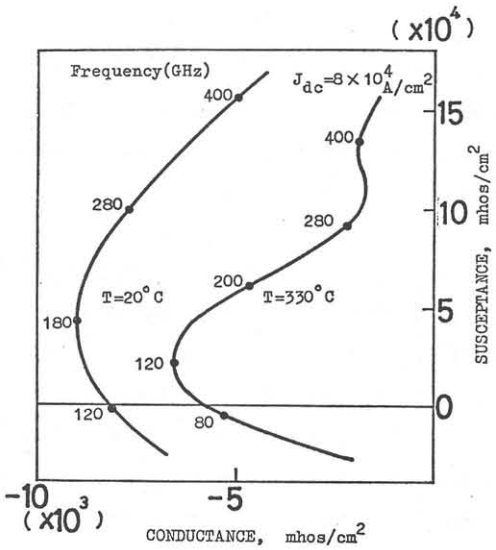


Fig.1 Admittance for $p^+n\,n^+$ SDR, $n=4.5\times10^{17}/cm^3$ at current density, $8\times10^4 A/cm^2$.

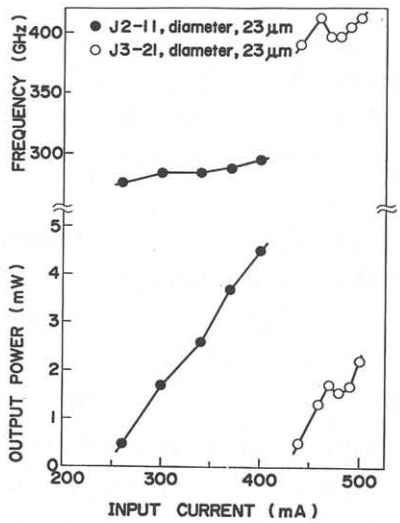


Fig.2 Output power and frequency against input current in 300 GHz and 400 GHz bands.