Digest of Tech. Papers The 8th Conf. (1976 International) on Solid State Devices, Tokyo

B-1-2

Submillimeter Wave Si P^+-P-N^+ IMPATT Diodes

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This paper describes recent results on the performace of Si p^+-p-n^+ IMPATT diodes made by ion implantations. Hitherto, pulse-driven[1] or CW[2] oscillation in the high frequency region about 200~300 GHz was achieved with p-n or p^+-n junction diodes. However, hole-drift diodes are expected to be superior to electron-drift ones for high frequency operation, due to a smaller hole diffusion coefficient.[3] In p-type diodes, as hole mobilities are smaller than electron, unswept layers should be removed and transition layer at the p^+-p interface should be made thin, in order to reduce a diode series resistance which causes to lower transfer efficiency and the upper limit of oscillation frequency.[4] Using the p^+-p-n^+ structure, p^+ layer can be made shallower and p^+-p interface more abrupt than conventional n^+-p-p^+ structure.

Device fabrication : High resistivity n^- epitaxial layers ($\rho \cong 1\ \Omega$cm) with approximately 0.5 μm thickness were used for the base materials. The p^+ contact layer was formed by boron diffusion and p-n^+ junction was formed by ion implantations. ^{31}P ions were implanted to form the n^+ layer at 350 keV to a high dose of 1.5×10^{13} ions/cm^2. Then ^{11}B ions were implanted at 60 keV to form the p region, and the dose was 8.0×10^{12} ions/cm^2. After annealing at 850 °C for 15 min, the wafer was thinned to be 5~10 μm, metallized by evapolating Ti-Au, and separated into individual pellets by airbrasive method. Then the pellet was thermally bonded to a copper heatsink with a quartz stud, and chemically etched to a proper diameter. Typical DC series resistance was 0.45 Ω for a diode of 17 μm diameter, and was comparable to that of p^+-n-n^+ diodes.[2] The doping profile designed and the electric field profile calculated at just breakdown are shown in Fig. 1. The peak field is 6.3×10^5 V/cm. The measured breakdown voltage was 11.4~11.6 V.

Oscillation performance : The diodes were tested in a full height 220 GHz waveguide (1.092x0.546 mm^2) with a hat structure cavity. Tuning was accomplished by changing a hat and sliding a back piston. Oscillation

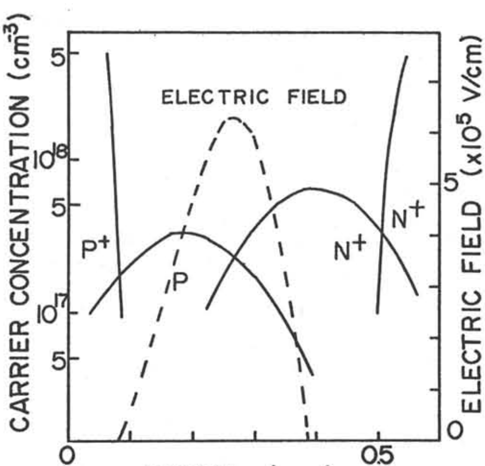

Fig. 1 DEPTH (μm)

frequency was measured by a two-dip frequency meter or detecting a voltage standing wave by a Si point contact diode. Output power was measured by a thin film thermo-couple calibrated by a 150 GHz band dry calorimeter. High pass filters were used for assurance of the measurements. The representative oscillation characteristics of the diodes are shown in Fig. 2 and 3. DC voltage began to decrease when oscillation built up, as shown in Fig. 2 and 3. This would be caused by RF induced negative resistance.[5] Using a spectrum analyzer, low frequency oscillation below several GHz was observed at the bias circuit. The maximum output power of 82 mW at 187 GHz with an efficiency of 2.5 % was obtained with the diode of 24 μm diameter (Fig. 2). At 285 GHz an output power of 7.5 mW was obtained with the diode of 17 μm diameter (Fig. 3). Oscillations above 300 GHz were also observed. At 330 GHz 0.7 mW was obtained. The highest oscillation frequency measured to date has been 394 GHz.

Conclusion : Practrical output powers have been obtained with the Si p^+-p-n^+ IMPATT diodes up to about 300 GHz. CW oscillation was observed at near 400 GHz.

Acknowledgements : The authors would like to thank H.Yamazaki for ion implantations, T.Makimura for valuable assistance in fabricating the diodes, Y.Sato, M.Fujimoto and K.Suzuki for encouragements.

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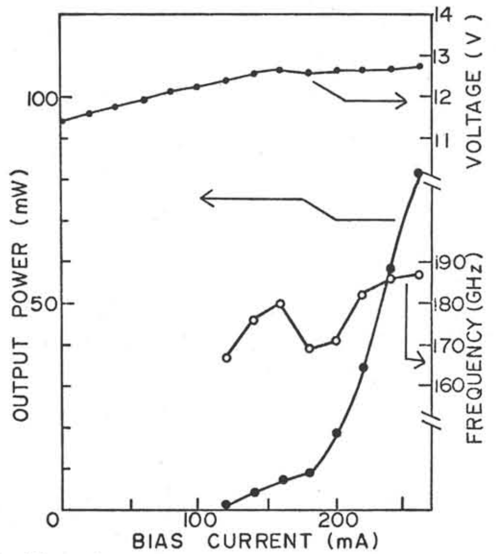

Fig. 2

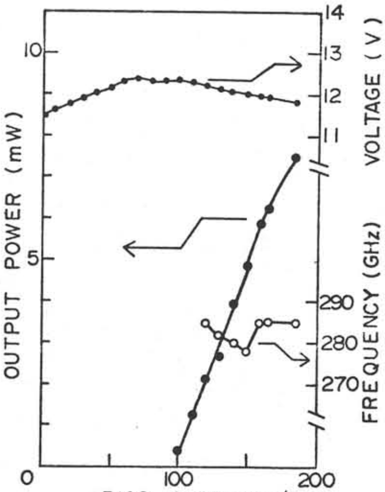

Fig. 3