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Computer study of TRAPATT

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__Introduction__ We have studied a behavior of TRAPATT diode by means of a computer simulation. The discussions in this paper are focused on the difference of a diode performance between pnn^+ and npp^+ diodes. The avalanche shock front propagations are completely different from each other, and npp^+ is more excellent for trapped plasma formation than pnn^+ diode. This originates from the fact that ionization coefficient for electrons is much larger than that for holes in case of silicon. ~~and germanium.~~ We have also confirmed that pnn^+ diode with a deep diffused p layer shows a similar behavior to npp^+ diode with regard to the shock front propagation.

__Dynamic behavior of TRAPATT__ Device parameters used in our simulation are as follows; doping density in an active region is $1.33\times10^{15}\,cm^{-3}$, length of the active region is about 4μm, breakdown voltage is about 100 V, oscillation frequency is 1~2 GHz, and ionization coefficients and velocity-field characteristics for electrons and holes are given by those for silicon.

Total current waveform is assumed to be rectangular and its rise time and fall time are one tenth of the oscillation period. Simulated voltage waveforms for pnn^+ and npp^+ are almost the same with each other, but the dipole and plasma formation time is a little shorter for pnn^+ than for npp^+ and the diode voltage in trapped plasma state for npp^+ is lower than that for pnn^+. (cf. Fig.1) Simulated efficiency for fundamental frequency is a few percent higher for npp^+ than for pnn^+ diode.

Major difference on the behavior of the diode between pnn^+ and npp^+ is the propagation of the avalanche shock front. Two types of shock front propagation are shown in Fig.2(a) and (b). Figure 2(a) for pnn^+ diode shows that the breakdown begins at the middle of an active region and avalanche region spreads over whole active region. On the other hand, in case of npp^+ diode, the avalanche occurs at n region and the shock front propagates toward p^+ region as shown in Fig.2(b). These differences originate from the fact that the generation rate G takes a maximum value at the middle of an active region in pnn^+ diode and at the n region in npp^+ diode.

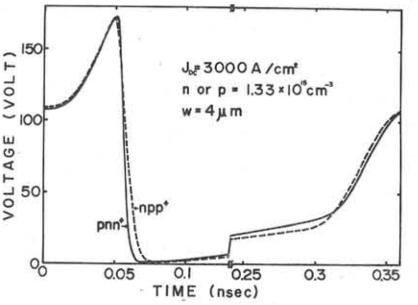

Fig.1 Diode voltage waveforms for pnn^+ and npp^+ diodes.

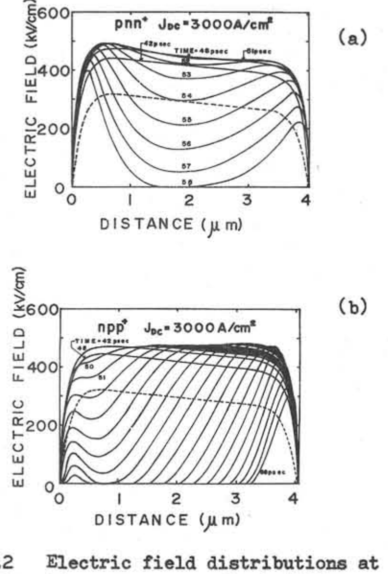

Fig.2 Electric field distributions at the breakdown process. Dashed line shows a static field distribution.

Static distribution of electric field, hole current J_p, electron current J_n, and doping profile are plotted in Fig.3(a) and (b) for pnn^+ and npp^+ respectively. Static current distributions for pnn^+ and npp^+ are different from each other. But this is not an essential cause of the difference of the avalanche shock front propagation. The difference comes from the fact that the ionization coefficient for electrons α_n is much larger than that for holes α_p in case of silicon, ~~and germanium.~~ The ionization coefficient for electrons takes a maximum value at the position where the electric field takes a maximum, so that the position where the generation rate G ($\propto \alpha_n J_n$) takes a maximum deviates from the field maximum position toward n^+ region in case of pnn^+ and toward n region in case of npp^+ diode. The trapped plasma formed as a result of shock front propagation for npp^+ is almost uniform in the whole active region, on the other hand, the amount of trapped plasma in pnn^+ diode decreases toward n^+ region. (cf. Fig.4(a) and (b)) The uniform trapped plasma is available for TRAPATT operation.

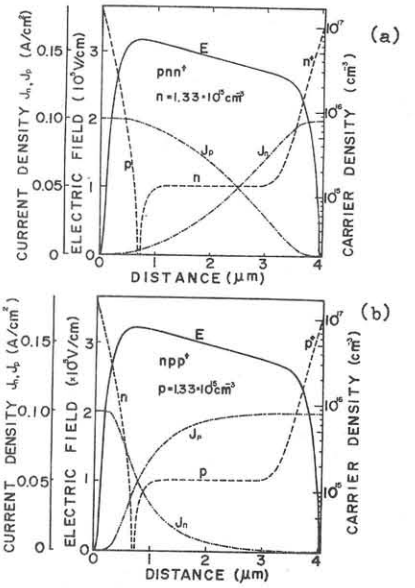

Fig.3 Static distributions of field and currents, and the doping profile.

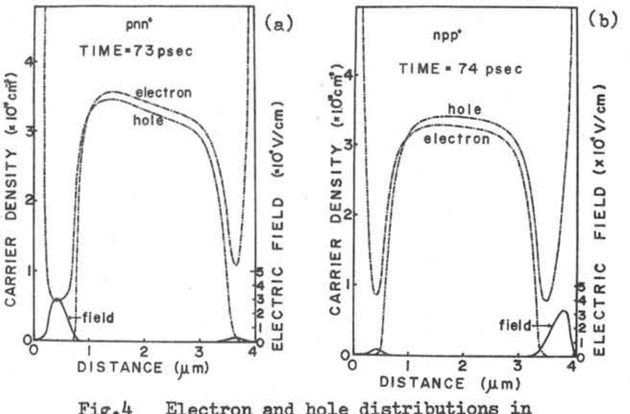

Fig.4 Electron and hole distributions in trapped plasma state for pnn^+ and npp^+ diodes.

We have fabricated a pnn^+ diode with a deep diffused p layer (5μm), and got out put power 64 watt, efficiency 53 % with a pulsed operation. We have also simulated pnn^+ diode with a deep diffused p layer. Figure 5 shows an avalanche shock front propagation in the deep diffused diode. Because peak position of the generation rate far deviates from that of the field toward n^+ region.

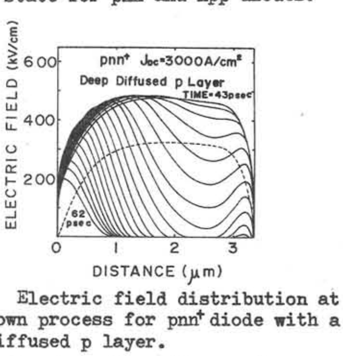

Fig.5 Electric field distribution at breakdown process for pnn^+ diode with a deep diffused p layer.

<u>Conclusion</u> Avalanche shock front propagations are different according to the doping profile of the diode. It is better to use a npp^+ diode or a pnn^+ diode with a deep diffused p layer so that a uniform trapped plasma may be realized in the active region.

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