HOPPING MULTI-DOMAINS

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In the present work the experimental data confirming the formation of several electric domains travelling simultaneously in the bulk of the p-type Si sample with the velocity c=2.5mm/sec in the region of temperature saturation of hopping conductivity are reported. The phenomenon was observed in the samples of lightly doped hole silicon with the low degree of compensation. The acceptor concentration was $7.3\cdot10^{16}cm^{-3}$ and the compensation was about 10^{-4}. A multi-domain was formed within the temperature range of 7-14K. Voltage pulses above the critical value and with the rising time lower than the Maxwell time of formation of a volume charge were applied to the sample. The result can be explained on the basis of Nguyen and Shklovskii theory predicting the negative differential resistance in the hopping conductivity region[3].

INTRODUCTION

Hopping transport can occur in semiconductors with decreasing temperature. In this case the return of carriers to impurity centres takes place. At a low impurity concentration the overlapping of electron states is low and the average distance between impurities exceeds the characteristic size of the wave function. Compensating impurities are the chief cause for the level scatter. Here, an impurity zone is formed that is a set of discrete states not connected with each other and scattered randomly in the energetic space. Randomness in the impurity arrangement also facilitates localization of electron states[1,2]. The ohmic conductivity is determined by an infinite cluster consisting of Miller-Abrahams equivalent grid resistances.

Each cell of the cluster called a critical sub- of the size of L_0 can contain dead ends. In the moderately strong electric field $eEL_0>>kT$ an electron, moving opposite to the field can easily get into such end. However, the probability to come out of it is $\exp(eEL_0/kT)$ times lower than the probability to get into it. The main role is played by those ends the probability of getting out of which opposite to and along the field is equal. Such dead ends are traps for the electron where it gets stuck for some time. In the case of weak compensation, the conductivity is determined as $\sigma(E)= \sigma(0)\exp(-eEL_0/kT)$. If we differentiate this expression, we obtain that in the E fields exceeding a certain critical value E_t, $E>E_t$, a negative differential resistance occurs[3,4]. This situation is realized in the studied *p*-type-Si with the acceptor concentration of $7.3\cdot10^{16}cm^{-3}$, with sufficiently weak compensation $k\approx10^{-4}$, where low-frequency current oscillations were observed on the current-voltage characteristics with sublinear dependence, beginning from the critical field E_t[5, 6].

In [7] it was shown that current oscillations observed in the external circuit were due to an electric domain travelling in the bulk of the sample. The statistical current-voltage characteristic could not be observed experimentally since in [3] the estimations were performed for an ideally homogeneous sample. As for the real sample, any inhomogeneity caused redistribution of the supply voltage. This is precisely the inhomogeneity where a hopping domain began to develop. A similar effect, but on another physical phenomenon was observed by Gunn[8] in GaAs and InP crystals.

EXPERIMENTAL RESULTS

In [5], in the samples of lightly doped and weakly compensated boron-doped p-Si, on the current density *j* vs. electric field *E* curve, with slowly increasing field E with *t* the sublinear character of the current-voltage characteristic changes to a sufficiently long portion of current instability. This portion extended up to the impurity breakdown. Here, beginning from the threshold field E, the amplitude of low-frequency current oscillations with increasing field E, as has been mentioned above, decreased gradually, was of a periodic character and then the dependence j(t) became “chaotic” [5]. For one of the studied samples with the acceptor concentration $7.3\cdot10^{16}cm^{-3}$ and compensation $k\approx10^{-4}$ the threshold voltage was Uc=56v.

To establish the processes occurring in the current instability region, a small field range near the threshold voltage Uc and the field range where current oscillations became of a “chaotic” character at temperature 10K were considered. Fig.1 (*a*).

First let us consider a small, about two volts, voltage range near the threshold value Uc=56v. The investigations have shown that indeed, according to [5], the current oscillations were periodic near the threshold field Uc. However, the current oscillation amplitude first increased slightly with increasing voltage, reached a maximum value and only afterwards began to decrease. To explain the behavior of the amplitude in this small field range, a dependence of the current pulse shape for several fixed supply voltages in the sample was considered. The current pulse shape at Uc=56v is shown in Fig. 1 *(b)*. Here, the current pulse shape remained unchanged both in the voltage oscillator mode and for the supply voltage pulse. In the voltage oscillator mode a series of current pulses separated by some time interval was observed; with increasing supply voltage this time interval decreased and at the same time an increase of the current pulse amplitude was observed (not shown in the figure). The existence of this time interval can be explained by the rearrangement of current paths of the infinite cluster[2]. The study of the distribution of the potential varying with time in the sample showed that in this field range near Uc there is one domain in the sample[7], Fig.2(*a*), that becomes “stronger” with the field. The next domain does not occur until the previous one goes to the anode and it is clear that no redistribution of the supply voltage to the next domain takes place. This can explain the behaviour of the current oscillation amplitude in the studied field range, Fig.1(*a*).

Let us consider the portion (in the region of 60V) on the current-voltage characteristic where current oscillations were of “chaotic” character, Fig.1 *(a).* Similar to 56 V, we first apply the supply voltage to the sample in the voltage oscillator mode and then supply voltage pulses with the width equal to the domain transit time. Consider Fig. 1(*d*) and Fig. 1*(c*). In Fig.1 *(d)* we see a series of current pulses the shape of which corresponds to application of the voltage U=60V to the sample in the voltage oscillator mode. In Fig 1(*c*) we see part of one current pulse the shape of which corresponds to application of the supply voltage pulse U=60V to the sample with the width equal to the domain transit time. The comparison of the shapes of the two current pulses suggests that in Fig.1(*d)* a redistribution of the supply voltage between the domain going to the anode and the domain being formed on the cathode takes place. In Fig.1(*c*) no such redistribution of the supply voltage occurs. The comparison of the shapes of the current pulses given in Fig.1*(d)* and Fig.1*(c)* shows that the current pulse amplitude in Fig.(1*(c)* is twice as large as that in Fig.1*(b).* Now let us consider the curves in Fig.2*(a)* and Fig.2*(b)*. In these figures the dependence of the distribution of the potential V

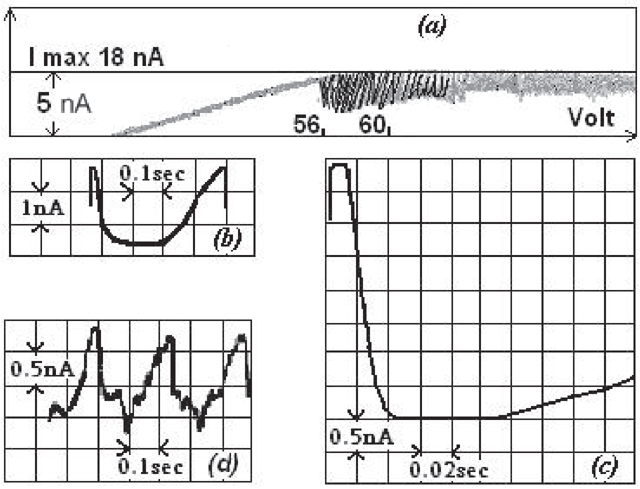

Fig.1. (*a*) – a portion of the current-voltage characteristic at the supply voltage scanning with the velocity of 0.6 V/sec.; (*b)* - a current vs. time dependence when a threshold supply voltage pulse Uc=56V with duration equal to the domain transit time is applied to the sample; (*c)* – the same as in (*b*) but for the voltage U=60V>Uc; (*d*) – the same supply voltage U=60v>Uc as for (*c*) but with the fixed value is applied to the sample. In all the cases the maximum current did not exceed 18 nA.

vs. time along the sample surface (curves I) is given. There, the variation of the potential derivative with time is also shown (curves II). In both cases the supply voltages Uc=56V – curve (*a*) and Uc=60V – curve (*b*) were applied to the sample. It is obvious that the potential difference for 60V was twice as much as for 56V. On the time dependence of the potential derivative in Fig.2(*b*) (curve II) two triangular formations are seen. It should be mentioned that the rise time of the supply pulses applied to the sample was lower than the Maxwell time of volume charge formation. Thus, the observed picture can be associated with the formation of two simultaneously moving hopping domains.

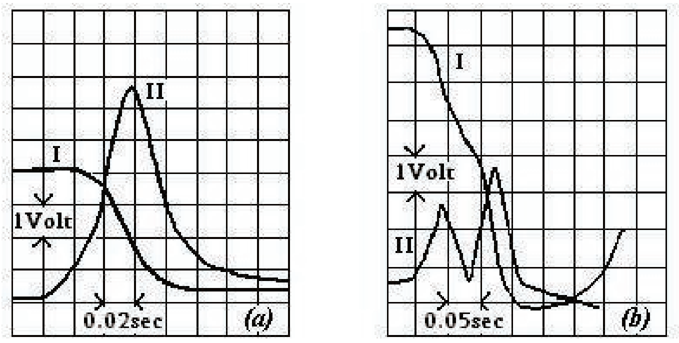

Fig.2. (*a*) – dependence of the potential *V* on time *t* (curve I) and of the potential derivative on time (curve II) at a distance of ≈0.4 mm from the cathode when the threshold supply voltage Uc=56V with the width equal to the hopping domain transit time is applied to the sample; (*b*) – the same as (*a*) but for the voltage U =60v >Uc.

The studied potential distribution was performed using probes. The probes travelled along the surface by means of special manipulators. The probes were connected to the oscillograph through a triaxial cable.

If submillimetric radiation is directed toward one of the domain, this domain can be extinguished and the supply voltage can be redistributed to the second domain

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