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B—7—2 Current-Voltage Characteristics of Super-Normal Multi-Layers

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It is known that semiconductor-superlattice structure exhibits nonlinear I-V characteristics with negative resistance [1]. Since quasi-particles in superconductors are thought to possess properties similar to the carrier in semiconductors, the behavior of the quasi-particle current in superlattice structure with spatially varing energy gap composed of alternate S-N multi-layers is an interesting object to study in connection with possibly incidental effects such as Josephson effect and nonequilibrium superconductivity.

We made measurements on the I-V characteristics of the multi-layer SN structure made of Pb and Cu at 4.2°K with the help of X-Y recorder. Figure 1 (a) is the geometry of the multi-layer specimens studied. Ten Cu layers each with thickness 30 nm compose alternate array with eleven Pb layers each with thickness 100 nm. The junction area is 2x2 mm^2. I-V characteristics observed in some specimens are asymmetrical with respect to the applied current direction as shown in Fig 1 (b). At the same time in almost all specimens are found many bendings in their I-V curves as seen in Fig. 1 (b) and (c). The values of the voltage and current at bending points are plotted in Fig. 1 (d) for several specimens. Figure 1 (c) represents also the influence of the magnetic field which is applied in parallel with the plane of the multi-layers and perpendicularly to the current there. It is seen that the I-V curves tend to ohmic relation with the increase of magnetic field.

In order to give a clear explanation to the observations, it is conceived to be necessary to have informations about the I-V characteristics of SN structures with simpler combination such as SNS and NSNSN. As to SNS structure we carried out measurements for specimens with geometry given in Fig. 2 (a). On specimens with thick N layer (∿100 nm) we again observed I-V curves with bendings as seen in Fig. 2 (b). (V,I) values at bending points are plotted in Fig. 2 (c) for two specimens. On the other hand quasi-particle tunneling characteristics as given in Fig. 2 (d) are observed in specimens with relatively thin N layer as expected. In specimens with thick N layer the super-normal particle interchange seems to be inevitable to maintain the current continuity. Since phonon emission and absorption are incidental to the particle interchange with phonon energy about the local energy-gap value at the SN interfaces, the bendings in the I-V curves may be related to the creation and annihilation of phonons.

On NSNSN structure more drastic phenomenon is observed in specimens with relatively thin medium N layer. Figure 3 displays an example of the observed I-V relations. When the applied current exceeds a threshold, an abrupt increase of the specimen voltage and the following unstable nonlinear I-V characteristics with negative resistance are observed. The threshold increases with the application of small magnetic field (∿10 G) or with the deterioration of the specimen due to self-heating. The deterioration is so severe that the characteristic reduces to simple ohmic relation with less resistance after application of current much exceeding the threshold for several times. These properties seem to deny the possibility of explaining the instability by simple temperature rise in specimen incidental to the sudden cooling-condition change [2]. Considering the proximity effect in the medium layer, the energy gap there takes a finite value which is less than that in the neibouring S layers. Electron-like and Hole-like quasi-particles are injected into S layers from the outside N regions. When the diffusion length is larger than the thickness of S layers, the quasi-particles recombine at the central energy valley emitting phonons. If stimulated emission is possible, the situation is similar to the photon emission in a double-hetero-junction-semiconductor laser.[3]

1) R. Tsu and L. Esaki, Appl. Phys. Lett. 22, 562 (1973).

2) W. J. Scokpol, M.R. Beasley and M. Tinkham, J. Appl. Phys. 45,4054 (1974).

3) I. Hayashi, M.B. Panish and F.K. Reinhart, J. Appl. Phys. 42, 1929 (1971).

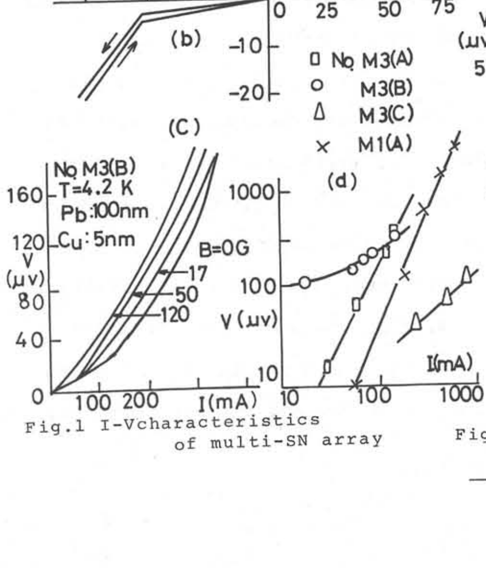

Fig.1 I-Vcharacteristics of multi-SN array

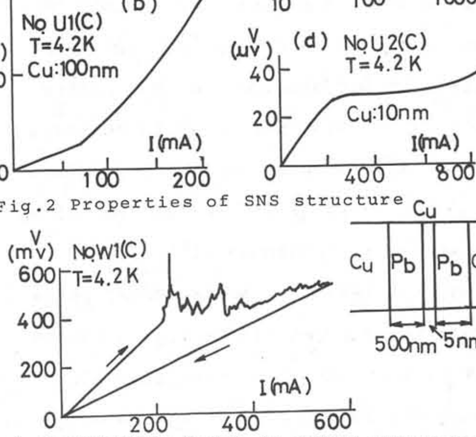

Fig.2 Properties of SNS structure

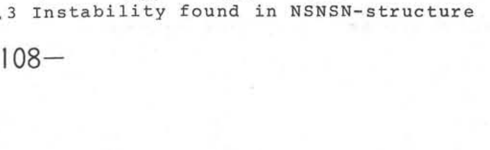

Fig.3 Instability found in NSNSN-structure