M. A. Obolenskiĭ. *Superconductivity and energy spectra of layered dichalcogenides of transition metals.* Interest in the study of superconductivity in systems with low dimension was stimulated by the theoretical works of Little[1] and V. L. Ginzburg,[2] in which possible mechanisms for raising the critical temperature in such systems were studied.

The spectrum of experimentally realized metallic (conducting) media with low dimension is now quite wide. It includes thin films, two-dimensional sandwich structures, semiconductor MIS structures, dichalcogenides of transition metals (DTM), organic superconductors, and the recently discovered high-temperature superconductors based on oxides of rare-earth and transition metals, in which strong anisotropy of the superconducting characteristics was observed.

The special interest in the appearance of superconductivity in DTM is explained by the unique possibility of studying the superconducting state experimentally under conditions when the two-dimensionality varies owing to intercalation and by the coexistence of superconductivity and partial dielectrification of the electronic spectrum owing to the existence of a phase transition of the charge density wave (CDW) type, preceding the superconducting state, in a number of these compounds.[3,4]

In this resport the experimental data on the normal and superconducting states in the 2H–$NbSe_2$ compound (both pure and intercalated with hydrogen, deuterium, and TCNQ), the results of investigations of the phonon spectrum by the method of point-contact spectroscopy,[5] the nonsteady-state Josephson effect along and across the layers, and the experimental realization of a transition from the 2H–$NbSe_2$ superconductor to $ReSe_2$ semiconductor by substituting rhenium atoms for niobium atoms, are analyzed.[6]

The study of the phonon spectrum in 2H–$NbSe_2$ by the method of point-contact spectroscopy along and across the layers revealed low-frequency excitations at energies near 5 meV, which can be explained by oscillations of the amplitude and phase of CDW. The point-contact spectra are sharply anisotropic. Comparison of the positions of the features in the point-contact spectra with the features computed in the theoretical models shows that the agreement is good at low energies ($\sim$40 meV). At energies above 40 meV, however, features absent in the theoretical models are observed in the point-contact spectra. The study of the nonsteady-state Josephson effect showed that the superconducting pairing along and across the layers is of the singlet type. A typical experimental point-contact spectrum is shown in Fig. 1. This figure also shows the theoretically computed curves $\omega(k)$ for comparing with experiment.[5]

Analysis of the temperature dependence of the second critical field $H_{c2}(T)$ shows that the positive curvature in the situation when the magnetic field is oriented parallel to the layers is characteristic for virtually all layered systems, and in particular for DTM. The positive curvature in the dependence $H_{c2}(T)$ can be realized experimentally by creating a spatially nonuniform superconducting state, or by layering, or by creating periodic modulation of impurities. The positive curvature can be explained on the basis of a model in which the orbital effect is different for different orientations of the magnetic field.[7,8]

Experiments on the effect of uniaxial pressure up to 2 kbar, applied perpendicularly to the layers, show that the critical temperature of the superconducting transition increases as the pressure increases up to $P = 1.4$ kbar, and then

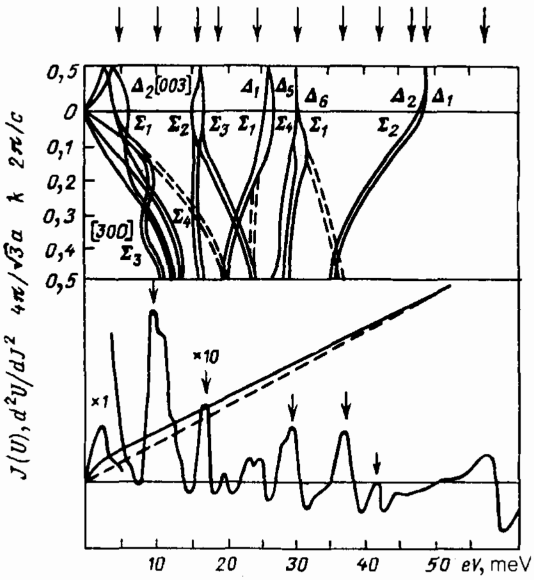

FIG. 1.

decreases, while at higher pressures its behavior is identical to the data presented in Ref. 9.

This result can be explained based on the assumption of a phase transition of order 2.5. The critical temperature at the maximum equals 10.4 K. The starting temperature at $P = 0$ equals 7.2 K.

In experiments on intercalation with TCNQ molecules (acceptor) it was found that the temperature at which the CDW transition appears in 2H–NbSe_2 increases and the critical temperature T_c decreases. In addition, a semiconductor-metal transition is observed in the temperature dependence of the electric resistance. The results are analyzed based on the model of a disorder-order transition in the intercalation system.[10,11] Hydrogen and deuterium with definite concentrations can form in 2H–NbSe_2 a superlattice (periodic spatial modulation of the concentration), which is dictated by the domain structure of the incommensurate CDW. The hydrogen and deuterium decorate the domain walls; this is reflected in the dependences $H_{c2}(\theta)$. In this situation $H_{c2}(\theta)$ has maxima when the magnetic field vector coincides with the superlattice vector.[12] In the process the superconducting characteristics H_{c2}, j_{c2} (critical current), and T_c are intensified after each cycle of transferring the sample from the superconducting state into the normal state by means of current and magnetic field ("conditioning" effect).[13] The topology of the superstructure can be changed by increasing the hydrogen in the moving vortex lattice; this is observed experimentally (Fig. 2). The explanation of the results obtained is based on the model of random metal networks, proposed in Ref. 14.

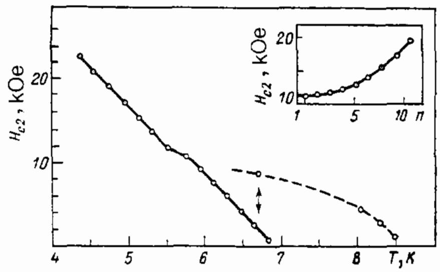

FIG. 2.

Experimental studies of the $Re_x Nb_{1-x} Se_2$ system established that the existence of superconductivity in this sytem depends on the concentration. Carrier localization effects are observed at a definite rhenium concentration.

The applied aspects of superconductivity in layered chalcogenides and the prospects for further studies are analyzed.

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