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THERMAL EXPANSION AND ELECTRIC CONDUCTIVITY OF SEMICONDUCTING $CuFeS_2$ FILMS AT LOW TEMPERATURES

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The thermal expansion and electric conductivity of semiconducting antiferromagnetic films were measured down to 2°K. 'Vanishing' of the resistance and a jump in the thermal-expansion coefficient were observed in the limited region $88 < T < 90$°K. This is taken as evidence of a superconducting transition.

To observe superconductivity and the quantum temperature size effect (QTSE) we investigated the thermal expansion and the superconductivity of films of the semiconductor $CuFeS_2$.

This chalcopyrite was synthesized from the compounds SuS and FeS [1, 2]. An x-ray phase analysis has shown that the product is $CuFeS_2$ of stoichiometric composition with tetragonal structure. Experimental studies [1 - 4] of a bulky sample yielded the carrier density $8 \cdot 10^{18}$ cm^{-3}, the width of the forbidden band 0.53 eV, the mobility 30 cm^2/V-sec, the thermal-emf coefficient 480 μV/deg, and showed that $CuFeS_2$ is an antiferromagnetic semiconductor with Neel temperature 823°K. An important feature of this substance is the presence of two ionic states $Cu^{1+}Fe^{3+}S_2^{2-}$ and $Cu^{2+}Fe^{2+}S_2^{2-}$ with ionic and covalent bonds) this exerts an appreciable influence on the kinetic and thermodynamic properties of the material.

The films were obtained by thermal evaporation of $CuFeS_2$ in a vacuum of $\sim 5 \times 10^{-5}$ mm Hg at parallel and perpendicular placements of the substrate surface relative to the axis of the conical tungsten evaporator.

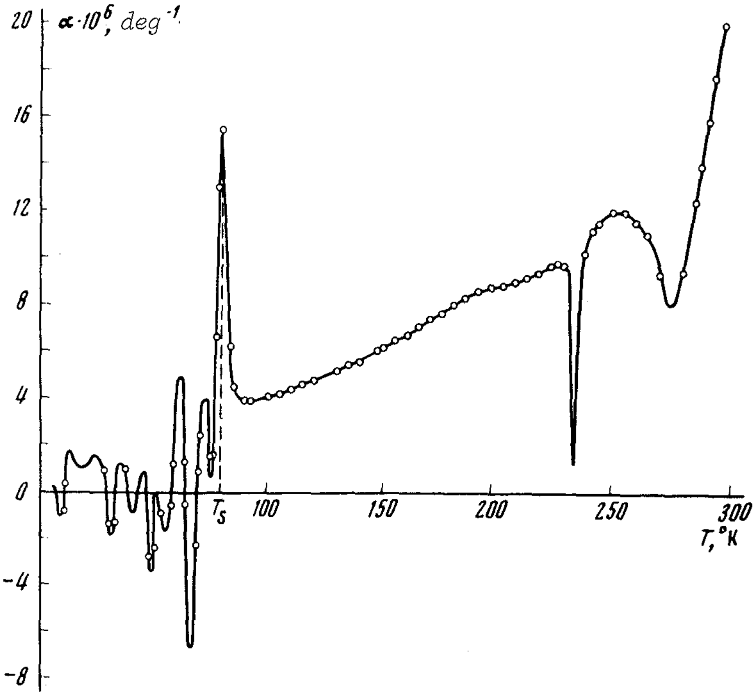

Fig. 1. Temperature dependence of thermal expansion of $CuFeS_2$ film approximately 400 Å thick.

It is known that when such substances are condensed on plane glass substrates, the magnetic moments have preferred directions. Taking these features into account, we evaporated the films on a glass helix that was displaced parallel to itself along the axis of the evaporator, with the aid of a special device. The thermal expansion was measured from 4.2 to 300°K by the precision bispiral method of Lazarev and Sudovtsov [6].

Figure 1 shows the dependence of the thermal expansion coefficient (TEC) of a $cuFeS_2$ film of thickness ∿400 Å with allowance for the expansion of the glass. It is seen that in the range 4.2 - 79°K the TEC assumes negative values in certain temperature intervals and a QTSE is observed, with an amplitude that increases exponentially with the temperature [8], just as in the case of CuS [7]. In addition to the fundamental periods, additional periods of oscillation are observed. At 79°K, the TEC experiences a jump in analogy with the second-order phase transitions. The TEC oscillations

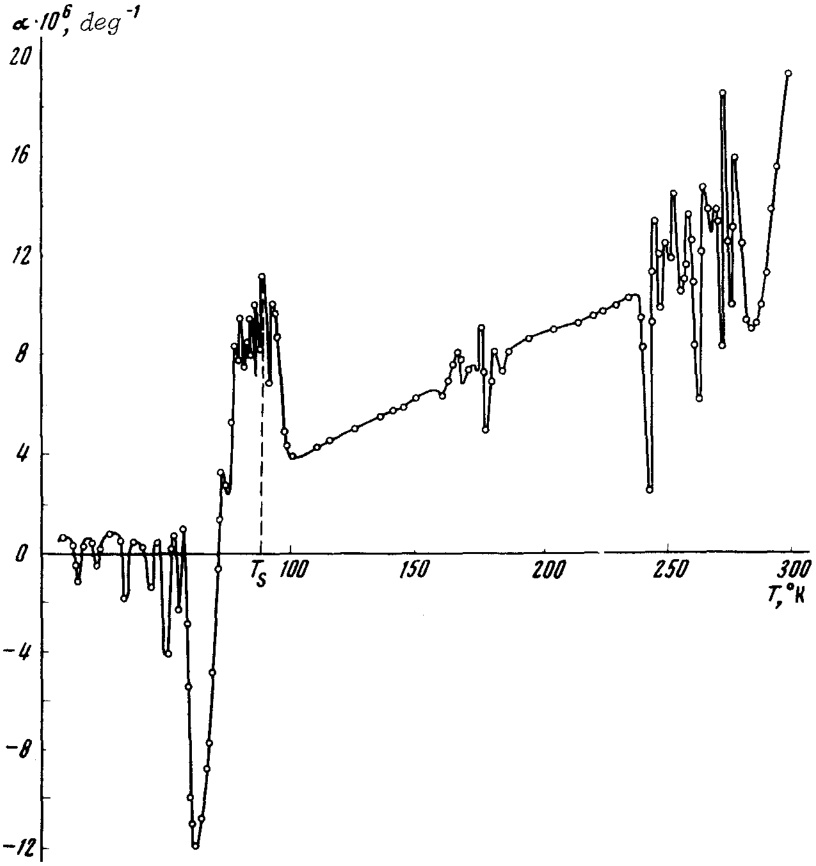

Fig. 2. Temperature dependence of thermal expansion of $CuFeS_2$ film approximately 200 Å thick.

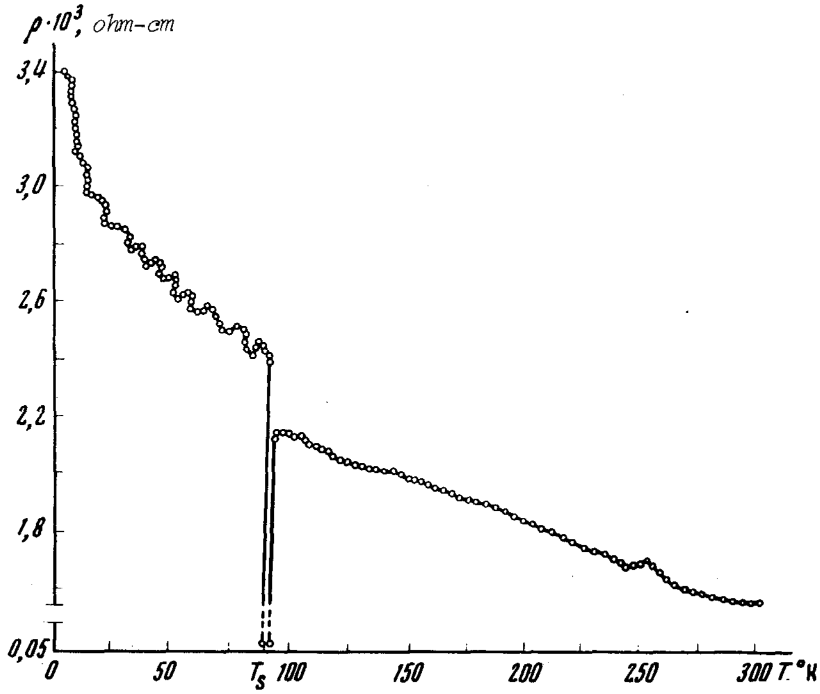

Fig. 3. Temperature dependence of resistivity of $CuFeS_2$ film approximately 200 Å thick.

vanish above this temperature.

An analogous picture is obtained also for a film ∿200 Å thick, where the transition takes place near 90°K, except that oscillation of the TEC takes place in the vicinity of this temperature (Fig. 2). In the 240 - 280°K region there is again a jump of the TEC, due apparently to an antiferromagnetic transition.

To explain the character of the transition at 90°K, we measured also the electric conductivity of $CuFeS_2$ films down to 2°K. Figure 3 shows the dependence of the resistivity ρ on the temperature of a film ∿200 Å thick, also obtained on a glass flat substrate by parallel displacement around the evaporator. We see that in this case, too, the temperature oscillations of ρ appear up to 88°K, where a 'vanishing' of the resistance is observed in a narrow temperature region of approximate width 2°. The resistance decreases in this case from 483 to 12 ohms, i.e., by an approximate factor 40; at the upper limit of the dip the resistivity is $2.42 \cdot 10^{-3}$, and in the lower $\sim 6 \cdot 10^{-3}$ Ω-cm. The latter is still not the lower resistance limit. In this case, the measurement of the lower resistance limit is limited by the methodological capabilities. Above 90°K, the resistance is restored jumpwise and retains its previous dependence of ρ on T. In the case of perpendicular condensation, the resistivity has a semiconducting character, without any singularities, just as in bulky samples. It is also of interest to note that the aforementioned phenomenon, a jump in the resistance and the TEC, is observed in films in which the QTSE takes place.

Thus, the 'vanishing' of the resistance at 89°K and the observation of a second-order phase transition determined by a jump in the TEC allow us to state that this is a superconducting transition due to the Coulomb interaction of electrons of different groups, in accord with the theory of Kogan, Kresin, and Tavger [9, 10]. According to this theory, the transition takes place in a limited temperature region, above and below which the superconductor remains in the normal state.

The observed phenomenon has a rather complicated character, since an important role is played apparently, in addition to the indicated mechanism, by the magnetic anisotropy of the properties as a function of the film condensation condition. In addition, the stoichiometry can become upset when so complicated a compound is evaporated. Both the superconductivity and the QTSE vanish when one of the foregoing conditions is violated.

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PASSAGE OF MICROWAVES AND CURRENT THROUGH A METALLIZED FILM EVAPORATED BY A LASER FLASH (PULSED WINDOW FOR MICROWAVES). PRODUCTION AND USE OF STEEP MICROWAVE FRONTS

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It is shown that a metallized film is evaporated by a short laser pulse it is possible to obtain short microwave emission fronts of length amounting to a fraction of the laser pulse duration. It is also shown that evaporation of a metallized current-carrying film by a laser flash interrupts the current abruptly and leads to appearance of an overvoltage. The possibility of using electromagnetic pulses with steep fronts are considered. It is noted that such pulses cause directed electron motion and produce a dc component of the magnetic field.

We describe here experiments on rapid laser triggering of microwave radiation and on current interruption, and review the possible applications of microwave radiation with steep leading fronts or trailing edges.

1. *The passage of microwave radiation and current through a metallized film evaporated by a laser.* It is known that laser radiation can cause rapid evaporation of a metal layer. This phenomenon is used, in particular, to shorten the leading front of a laser pulse by placing in the path of an unfocused powerful light beam a film with thin metallic coating, which is evaporated within a time on the order of ten nanoseconds. (The evaporation time does not exceed, in any case, the heating time $t_T \sim d^2/\kappa \simeq 1 - 10$ nsec at an initial layer thickness $d \lesssim 0.1 - 0.3$ μ and at a temperature conductivity $\kappa \simeq 0.1$ cm^2/sec.)

2. We have investigated the passage of microwave radiation through a metallized film as it was evaporated by a laser pulse. The delay and transmission front could be quite long, owing to the long lifetime of the thermal plasma produced by the heating of the metal and by surface breakdown. While not dense, this plasma did act on the microwaves. The experiments have shown, however, that the transmission time was short, of the order of the film evaporation time.

The experimental setup is shown in Fig. 1a. We used a Q-switched neodymium laser (1) that produced a pulse with half-width 20 nsec and energy up to 5 J. The laser beam passed through a metallized polymer film (3) placed at an angle 45° to the laser beam. A microwave beam from an oscillator (4) of wavelength $\lambda = 1$ cm was directed normal to the film, and on the