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TEMPERATURE DEPENDENCE OF HYPERFINE INTERACTION LINES IN EPR SPECTRA OF PHOSPHORUS IN SILICON

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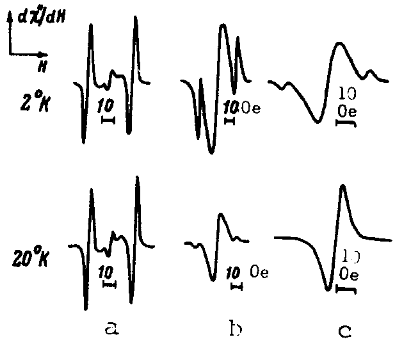
In an investigation of the temperature dependence of the spectra of electron paramagnetic resonance (EPR) in n-type silicon doped with phosphorus, it was observed that the hyperfine-interaction lines behave differently in spectra of samples with different phosphorus concentrations. The figure shows the EPR spectra $d\chi''/dH = f(H)$ at two temperatures (2 and 20°K) for samples with phosphorus donor impurity concentration $N_D = 2 \times 10^{17}$, 4.5×10^{17}, and 6×10^{17} cm^{-3}. We see that, unlike the sample with $N_D = 2 \times 10^{17}$ cm^{-3}, in the samples with $N_D = 4.5 \times 10^{17}$ and 6×10^{17} cm^{-3} the intensity of the hyperfine-interaction lines decreases rapidly with increasing temperature.



EPR spectra: a - $N_D = 2 \times 10^{17}$, b - $N_D = 4.5 \times 10^{17}$, c - $N_D = 6 \times 10^{17}$ cm^{-3}.

The difference in the temperature dependence of the hyperfine interaction lines in the investigated silicon samples is connected, in our opinion, with the different nature of the paramagnetic centers which make the main contribution to these lines at different phosphorus concenterations.

At a donor concentration $N_D = 2 \times 10^{17}$ cm^{-3}, the hyperfine interaction lines are due principally to isolated atoms of phosphorus, since the overlap of the wave functions is insignificant at this concentration [1]. There is therefore no exchange of electrons between the neighboring atoms to lead to a decrease in the number of bound electrons, and consequently the intensity of the hyperfine interaction lines is practically independent of the temperature.

At donor concentrations $N_D = 4.5 \times 10^{17}$ and 6×10^{17} cm^{-3}, there is considerable overlapping of the wave functions, as evidenced by the presence of an intense central line in the spectrum. In this case the hyperfine interaction lines are due essentially to groups of interacting atoms [1]. As a result, an increase in the temperature causes an increase in the frequency of the jump between atoms, i.e., an intensification of the delocalization of the electrons. As a result, an increase in temperature is accompanied by a decrease in the intensity of the hyperfine interaction lines and an increase in the intensity of the central line.

In addition, a narrowing of the central line is observed with increasing temperature. It occurs most effectively in a sample with phosphorus concentration $N_D = 6 \times 10^{17} cm^{-3}$. As noted in [2], a similar effect is observed in germanium and can be due to the jumping of the electrons between atoms, a process occurring with phonons taking part.

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[2] D. Wilson, Phys. Rev. 134, A265 (1964).

POSSIBLE CONNECTION BETWEEN K_2^0 DECAY AND STATISTICAL IRREVERSIBILITY

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Data on the decay of K_2^0 mesons into two pions offer evidence of lack of CP invariance and consequently of t-invariance in this process [1].

Attempts to explain this result without foregoing CP invariance as a whole are based on the assumed existence of external fields that cause the K_1^0 and K_2^0 particles to be superpositions of CP-even and CP-odd states [2]. The observed effect is then proportional to the external action (the proportionality coefficient is not anomalously large) which must therefore be sufficiently large.

We wish to call attention to another possible approach. Time-irreversible processes are common in macroscopic physics. However, in the physics of elementary particles there are no models or theories in which dissipative processes are involved. The most highly developed theory of this type - the statistically-hydrodynamic theory of multiple particle production in collisions between high-energy nucleons - is the Fermi-Landau theory, which does not discuss in explicit form the question of absence of t-reversibility. It is clear, however, that if there is a system of interacting particles or fields with a large number of degrees of freedom, then statistical theory is generally speaking applicable to such a system. The basic principles are the same here as in macroscopic physics. We can assume, for example, that there is always an arbitrarily weak external interaction which, by virtue of the complexity of the system, can give rise to a strong effect (increasing exponentially in time) [3]. The intensity of the external action is then multiplied by a very large factor, which increases exponentially in time with increasing complexity of the system, i.e., with increasing level density, with increasing number of degrees of freedom, etc. [4].

The physical cause of such an "amplification" of the external action, the origin of which becomes essentially immaterial, is the instability of the regular motion in the complex system against an infinitesimally small disturbance.

It is perfectly correct to assume that the decaying particle (in our case K_2^0) is itself a system with a large number of degrees of freedom, and that the statistical approach is applicable to its time evolution. We note that statistical notions concerning the internal properties