Faraday rotation in the Appel-Overhauser model for inversion-layer electrons in Si. II

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We have previously calculated Faraday rotation in metal-oxide—semiconductor surface space-charge layers, with the use of the Appel-Overhauser model. Here we extend this work to study the dependence of the rotation on the electron-electron collision time τ_e. Results for the Drude model are also presented.

Cyclotron resonance observations of electron inversion layers on Si have given rise to a puzzle, which led Appel and Overhauser[1] to suggest that the system consists of two different types of degenerate electrons, characterized by their respective masses m_1 and m_2 and relaxation times τ_1 and τ_2. An important parameter entering into their model is the electron-electron interaction (*e-e*) scattering time τ_e. Taking $\tau_1=\tau_2\equiv\tau$, Appel and Overhauser have shown that for strong *e-e* interactions one obtains a single cyclotron resonance but that two resonance peaks are obtained in the case of $\tau/\tau_e=0$ (characteristic of noninteracting electrons).

Motivated by the desire both to test and understand more fully the Appel-Overhauser model, we have recently examined single-pass Faraday rotation θ in this sytem, in the limits of both weak ($\tau/\tau_e << 1$) and strong ($\tau/\tau_e >> 1$) electron-electron scattering.[2] Here we extend this work to the more complicated but more interesting case of *intermediate coupling* since investigations of Ref. 1 indicated, at least for the experiments presently of interest, that the appropriate regime is either strong or intermediate coupling. Thus, we are motivated to investigate the dependence of θ on τ_e. We have carried out an *exact* numerical calculation of Faraday rotation in the Appel-Overhauser model and in Figs. 1 and 2 we present some representative results.

In our notation, ω is the frequency of the electromagnetic radiation, m is the free-electron mass, m_1 and m_2 the effective masses of electrons 1 and 2, respectively, n_1 and n_2 the concentrations of electons, B the external magnetic field, ω_1 and ω_2 the respective cyclotron frequencies, τ_1 and τ_2 the collision times, ϵ_l the dielectric lattice constant, and l the length of the space-charge layer. The Drude model may be obtained from the Appel-Overhauser model by setting $m_1=m_2=0.19m$, $\tau_1=\tau_2\equiv\tau$, $2n_1=2n_2\equiv n^*$, and $\tau_e=0$.

In Fig. 1 we present results for θ versus photon frequency ω, and Fig. 2 is for θ versus the external dc magnetic field B, for various values of τ/τ_e. The single-pass rotation obtained from the Drude model is included for comparison.

It is of interest to compare Fig. 1 with the corresponding figure in our previous paper.[2] Many of the same parameters are used but in the latter, for display purposes only, we selected an arbitrary length (which was essentially of no consequence since θ is propotional to l and thus the whole θ curve scales as l). Now we have selected $l=100$ Å, which is of the order of the length of the space-charge layer along the direction of the applied static electric field. In addition, our previous investigation was restricted to $\tau_e >> \tau_{1,2}$ (in fact we selected[3] $\tau_e=10^{40}$ s, corresponding to two types of noninteracting electrons) whereas now we consider a range of τ/τ_e values. The τ/τ_e value of 10^{-2} is small enough to essentially correspond to the noninteracting situation.

In addition, we have selected considerably larger values for the concentrations $n_{1,2}$, since this corresponds to the regime in which experimental Faraday rotation investigations are being carried out.[4] This results in a radical change in the shape of the θ curve, as can be seen by comparing our previous curve[2] with the $\tau/\tau_e=10^{-2}$ curve of Fig. 1. In the former case, we found that the Faraday rotation has a zero, at a frequency intermediate between the cyclotron frequencies of the individual systems. Now we find that all values of θ displayed are negative and that much higher values of ω would be necessary to achieve a zero value for θ. The reason for this can be explained by the fact that, in the present situation, the plasma frequencies corresponding to m_1 and m_2 are 7.05×10^{13} s^{-1} and 4.74×10^{13} s^{-1}, respectively, both of which are

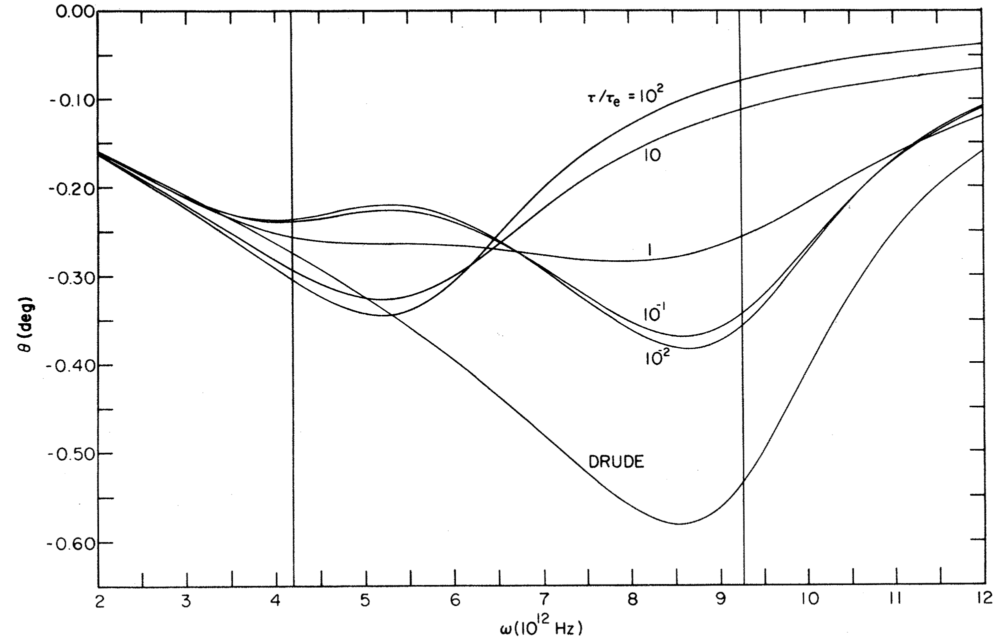

FIG. 1. Plot of the Faraday rotation θ vs angular photon frequency ω for the Appel-Overhauser model, for various values of τ/τ_e, using parameters $m_1=0.19m$, $m_2=0.42m$, $n_1=n_2=3.5\times10^{18}$ cm^{-3}, $\tau_1=\tau_2\equiv\tau=6\times10^{-13}$ s, $l=10^{-6}$ cm, $B=10^5$ G and $\epsilon_l=11.8$. The vertical lines indicate the corresponding values of $\omega_1=9.26\times10^{12}$ s^{-1} and $\omega_2=4.20\times10^{12}$ s^{-1}. The Drude model shown corresponds to taking $m_2=m_1=0.19m$, $\tau_e=0$ and keeping the rest of the parameters the same.

larger than the maximum value of 1.2×10^{13} which ω takes. Now, as we have shown recently,[5] in the case of a single-mass electron system, for values of the plasma frequency $\omega_p << \Omega\equiv(\omega_c^2+\nu^2)^{1/2}$,

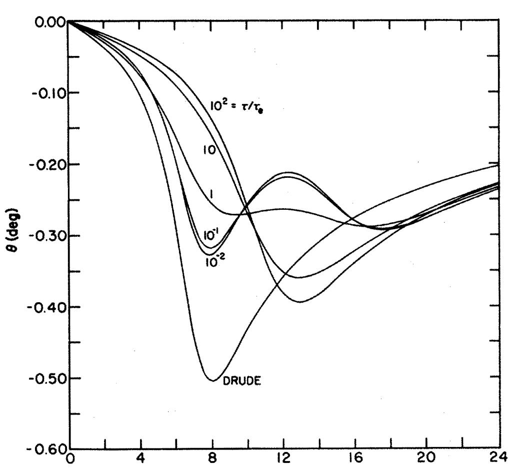

FIG. 2. Plot of the Faraday rotation θ vs the external magnetic field B for the Appel-Overhauser model using $\omega=6.455\times10^{12}$ s^{-1} and with the rest of the parameters the same as in Fig. 1.

where $\nu=\tau^{-1}$ and ω_c is the cyclotron frequency, a zero in θ occurs for $\omega=\Omega$. On the other hand, for $\omega >> \Omega$ the zero in θ occurs at an ω value equal to $0.866\omega_p$. In particular, we note that the "Drude curve" in Fig. 1 is such that θ is tending towards 0 as ω increase towards a value of $0.866\omega_p$. The situation is, of course, more complicated for the other curves (since there are two systems involved) but the same general trend is manifest.

It is noteworthy that the shape of the curves depends significantly on the value of τ/τ_e. In particular, as we go from smaller values of τ/τ_e to larger values, one of the peaks in the curves disappears. Thus, we have a potentially useful method for obtaining a handle on the strength of the e-e coupling.

Since we are dealing with a system with many variable parameters it is clear that a variey of other curves could be presented. However, we feel it is best to defer any further elaborations until some experimental Faraday rotation results have been obtained. Our colleague, Dr. H. Piller, is currently engaged in carrying out such experiments.[4]

Finally, we remark that the results discussed above refer only to the so-called single-pass Faraday rotation, i.e., multiple-reflection effects are neglected. We are presently investigating such effects.

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[1]J. Appel and A. W. Overhauser, Phys. Rev. B 18, 758 (1978).
[2]R. F. O'Connell and G. L. Wallace, Phys. Rev. B 24, 2267 (1981).
[3]There is a misprint in Fig. 1 of Ref. 1. The part which reads $\tau_2 = 10^{40}$ s should read $\tau_e = 10^{40}$ s.
[4]H. Piller (private communication).
[5]R. F. O'Connell and G. L. Wallace, Solid State Commun. 38, 429 (1981).