WAVELENGTH AND TEMPERATURE DEPENDENCE OF THE FARADAY EFFECT IN
Cd(1 − x)Mn(x)Te

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The wavelength dependence of the Faraday effect at fixed temperature
and the temperature dependence at fixed wavelength have been
measured in Cd(0.55)Mn(0.45)Te. These results can be explained quite
well using a simple exciton model and the known temperature
dependence of the magnetic susceptibility and exciton energy.

INTRODUCTION

ONE OF THE UNIQUE features of the semimagnetic semiconductors is the unusually large Faraday
effect that they exhibit [1]. Since the original observations, the large Faraday effect has been attributed to
exciton effects even though no careful comparison between theory and experiment had been made. This
behavior is different from most III-V and II-VI compounds where the contribution from excitons is
generally considered important only very close to the ex-
citon energy [2]. In this letter we examine the
wavelength and temperature dependence of the Farad-
ay effect and find that indeed a simple exciton model
provides a qualitative description of the observed
behavior.

EXPERIMENTAL

The temperature dependent measurements were
made using a He-Ne laser (633 nm) in the Faraday
geometry with the analyzer parallel to the initial
polarization. The magnetic field from a Varian magnet was
adjusted to provide a null in the transmitted light
intensity. The field between nulls was used to deter-
mine the Verdet constant. Typically this magnetic field
difference was about 18 kOe. The temperature of the
sample was controlled using a Varian nitrogen gas
flow system with a thermocouple at the sample. The
experimental results for Cd(0.55)Mn(0.45)Te are
shown in Fig. 1.

The wavelength dependence of the Faraday effect
was measured at room temperature using the various
lines of a krypton laser in the conventional Faraday
gamey. The analyzer was set at 45 degrees to the
input polarization so that modulation of the polarization
direction resulted in amplitude modulation of the
beam. A time varying magnetic field was generated by
placing the sample in a micro-strip line with the laser
beam perpendicular to the strip. The light beam was
modulated at 200 MHz and the signal detected with a
fast photodiode and a spectrum analyzer. Further
details of the experimental arrangement have been
published elsewhere [3].

WAVELENGTH DEPENDENCE

Recently a quantitative expression was derived for
the Faraday rotation θ produced by a simple
exciton [4]:

\[ θ = \frac{-19π}{18λn} \left( \frac{E_p^2}{E_e^2 - E_0^2} \right)^3 β N_c x \langle S_z \rangle, \]  

where \( n \) is the index of refraction, \( λ \) is the wavelength
of light in vacuum, \( E_p \) is the plasma energy, \( E_e \) is the
exciton energy, \( E \) is the photon energy, \( β \) is the
oscillator strength, \( β \) is the Mn-hole exchange interaction,
\( N_c \) is the number of cations per unit volume, \( x \) is the
Mn concentration, and \( \langle S_z \rangle \) is the thermal average of
the Mn spins along the applied field. In order to
compare this expression with the experimental results,
A comparable fit to the data can be obtained using models of the Faraday effect which attribute the photon energy dependence to interband transitions [2]. However, these fits require a bandgap that is smaller than the measured exciton energy. It would be possible to use equation (1) to predict the magnitude of the Faraday effect as well as the functional dependence if all of the parameters are known. However, the oscillator strength of the exciton is unknown. Instead we will use equation (1) and the measured Faraday rotation to estimate the oscillator strength of the exciton. Using the Verdet constant from Fig. 1, $E_v = 2.12$ eV, $E_v = 20$ eV [9], $\beta N_e = 0.88$ eV [10], $n = 3.0$ and estimating $\langle S_z \rangle$ from the known susceptibility, the oscillator strength necessary to explain the Faraday rotation within the framework of the simple exciton model can be shown to be about $f = 7 \times 10^{-4}$. This value can be shown to be reasonable by estimating the corresponding optical absorption using Smakula’s formula [11]. In this case no local field corrections are used since the exciton wavefunction is fairly extended and a Gaussian lineshape is assumed. Then:

$$N_v f = n (0.97 \times 10^{-7}) \times \Gamma,$$

(4)

where $\Gamma$ is the peak optical absorption in cm$^{-1}$, $\Gamma = 40$ meV is the full width at half height and the other parameters have been previously defined. This expression gives a value for $\Gamma$ of about $10^4$ cm$^{-1}$. Unfortunately the corresponding measurements in CdMnTe have not been made and this value can only be compared to the estimated peak absorption of $5 \times 10^4$ cm$^{-1}$ for the exciton in CdTe [9]. The agreement is reasonable considering the uncertainties in using Smakula’s formula [12] and the unknown effects of the Mn content on the exciton wavefunction.

This order of magnitude agreement shows that attributing the Faraday rotation completely to exciton effects is not unreasonable. However, the similarity in wavelength dependence for exciton and interband transition models means that a combination of both effects is not completely ruled out.

**TEMPERATURE DEPENDENCE**

Both exciton and interband transition models have the general functional form [1]:

$$\theta = \theta_0 (E_v, \langle S_z \rangle) F(x),$$

(5)

where $x = E/E_v$. All of the wavelength dependence is contained in the $F$ function and other dependences are contained in $\theta_0$. Without further specifying the functional form of (5) it can be shown that the temperature dependence is given by:
Table 1. Temperature dependent Faraday rotation in Cd(1 - x)Mn(x)Te

<table>
<thead>
<tr>
<th>Mn(%)</th>
<th>E/E₀</th>
<th>( \frac{1}{E_0 \frac{\partial \theta}{\partial T}} )</th>
<th>( \frac{1}{E_0 \frac{\partial E}{\partial E} \frac{\partial \theta}{\partial T}} )</th>
<th>( \frac{1}{E_0 \frac{\partial \theta}{\partial T}} )</th>
<th>( \frac{1}{E_0 \frac{\partial \theta}{\partial T}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>45</td>
<td>0.925</td>
<td>(-2.1 \times 10^{-1})</td>
<td>(+5.5 \times 10^{-1})</td>
<td>(+3.4 \times 10^{-1})</td>
<td>(+2.0 \times 10^{-1})</td>
</tr>
<tr>
<td>15</td>
<td>0.948</td>
<td>(-3.5 \times 10^{-1})</td>
<td>(+5.6 \times 10^{-1})</td>
<td>(+2.1 \times 10^{-1})</td>
<td>(+2.0 \times 10^{-1})</td>
</tr>
</tbody>
</table>

* From [6].

\[
\frac{1}{E_0 \frac{\partial \theta}{\partial T}} = \frac{1}{\theta_0 \frac{\partial \theta}{\partial T}} - \frac{1}{\theta_0 \frac{\partial E}{\partial E} \frac{\partial \theta}{\partial T}} \quad (6)
\]

This expression can be easily evaluated using known experimental numbers. The second term on the right side of equation (6) comes from the temperature dependence of the exciton or interband transition and is well-known [7, 8]. The dominant contribution to the first term is believed to arise from the temperature dependence of the Mn spin susceptibility [6, 13] which is also well-known. Thus the expected temperature dependence of the Faraday effect in these materials can be estimated without specifying the origin of the effect.

The room temperature calculated values are compared with the experimental results in Table 1. In column 3 is shown the temperature dependence of \( \theta_0 \). This temperature dependence is due principally to the magnetic susceptibility and thus is larger for the 15% Mn sample because the effective Curie–Weiss constant is smaller. There is also a small contribution from \( E_0 \) which has been included by assuming the simple exciton dependence from equation (3). In column 4 is shown the temperature effect due to the movement of the exciton energy which is quite similar in the two samples. In column 5 these two contributions are combined to give the total calculated temperature dependence. Note that the total calculated temperature dependence is the difference between the two contributions. The last column gives the measured temperature dependence of the Faraday rotation which is to be compared to the calculated numbers in column 5. The agreement is quite good for the 15% Mn sample and fair for the 45% Mn sample. Because the total effect is the difference of the terms in columns 3 and 4, the discrepancy for the 45% Mn sample could be explained by a 20% error in column 4. This error is plausible because the laser lines used to obtain \( \partial \theta/\partial E \) are quite widely spaced making it difficult to obtain an accurate value. This is not the case for the 15% Mn sample where the data points are closer together [6].

Thus the temperature dependence of the Faraday effect can be quantitatively explained by taking into account the temperature dependence of the exciton energy and the magnetic susceptibility.

CONCLUSIONS

In this paper we have shown that the Faraday rotation in Cd(1 - x)Mn(x)Te can be described by a simple exciton model. This model provides the correct functional form for the wavelength dependence and an estimate of the magnitude for the effect that is consistent with the exciton intensity in CdTe. The temperature dependence of the Faraday rotation in these alloys is quantitatively explained by considering the temperature dependence of the exciton energy and the magnetic susceptibility.

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REFERENCES