Magnetization of Dimensional Diluted Magnetic Semiconductors

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Received: December 24, 2026
Published: May 22, 2026

ABSTRACT

The one dimension, two dimension and the three dimension relation in case of concentration and temperature versus reduced magnetization have been over looked. Recently information technology is one of the important issues for the optical, electrical and magnetic properties of diluted magnetic semiconductors. One of the most useful aspects of semiconductors resides in their capacity to be doped with impurities, by which the electrical properties can be tuned be interpreted as a function of temperature and magnon concentration. DMs is of fundamental interest and may enable future spin-optoelectronic devices. In order to enable to them useful for such devices efforts have been made to develop diluted magnetic semiconductors (DMS) in which small quantity of magnetic ion is introduced in to normal semiconductors. ZnMnTe with face centered cubic structure and long-range antiferromagnetic ordering is study within the frame work of the Heisenberg model. The Hamiltonian includes exchange interactions with the nearest neighbors and Zeeman terms.

Keywords: Diluted Magnetic Semiconductors, Low Dimensional, Antiferromagnetic

INTRODUCTION

Information technology is one of the important issues in the 21st century. Developing alternative high speed and low energy consuming information technology is urgently needed [1]. The mass, charge, and spin of electrons in the solid state lay the foundation of the information technology we use today. Semiconductor devices generally take advantage of the charge of electrons, whereas magnetic materials are used for recording information involving electron spin. If both the charge and spin of electrons can be used to further enhance the performance of devices, so called spintronics, we may then be able to use the capability of mass storage and processing of information at the same time, thus leading to a brand new era of information technology [2,3,4-7].

Citation: Inkosa MT, Nigusa A. (2026). Magnetization of Dimensional Diluted Magnetic Semiconductors. Nanoparticle. 7(1):22.

DOI: https://doi.org/10.35702/nano.10022

DMS bridge the physics of semiconductors and magnetic since they show typical semiconductor behavior and they also reveal pronounced magnetic properties. Diluted magnetic semiconductors (DMS) in which the semiconductor cations are partially substituted by magnetic elements, is one of the important materials for the realization of spintronics. The rapid progress achieved in DMS technologies which use non-equilibrium growth methods, such as molecular beam epitaxy (MBE) the ferromagnetic transition was observed in II-VI, III-V and IV-VI semiconductor compounds. In most studied DMS manganese is used as a magnetic impurity. Manganese doped II-VI and IV-VI DMS mostly exhibit antiferromagnetism, spin glasses and paramagnetism, but they also show ferromagnetic transition at low temperatures.

The ability to synthesize DMS in low dimensional nanostructures could provide new building blocks for spintronics as well as open up new opportunities for fundamental physical studies [2,3]. Solid state magnetism and semiconductor physics are two of the most important areas of current research in condensed matter physics [4,8,6,9].

A semiconductor is typically smaller than $2eV$ (i.e. small energy gap) and room-temperature thermal energy or excitation from visible-light photons can give electrons enough energy for "jumping" from the valence into the conduction band. The energy gaps of some semiconductors are listed in Table 1. The small energy gap in semiconductor determines among other things the wavelengths of light that can be absorbed or emitted by the semiconductors.

Table 1: The energy gap of the most common semiconductors [18].

Semiconductor	**Energy gap (E_g) in E_v**
Germanium (Ge)	0.67
Gallium arsenide ($GaAs$)	1.42
Cadmium selanide ($CaSe$)	1.74
Indium arsenide ($InAs$)	0.46

Density of States and Dimensions of Materials

The peculiar characters between systems with different dimensions is their density of states $\rho(\epsilon)$ which is the number of states per unit volume in the energy ϵ and $\epsilon+d\epsilon$ [25]. Restriction of electron motion in one, two and three dimensions gives rise to discrete energy levels, in quantum dot, quantum wire and quantum well, there are additional degrees of freedom along unconfined directions.

Density of state in three, two and one dimension's materials

In three dimensions, there is no confinement in the direction of motion of electrons [10-28]. The only constrains is the periodic boundary conditions. The available states between k and $k+dk$ are contained in a shell of radius k and thickness dk, which has a volume $4\pi k^2 dk$. The electron states are uniformly distributed in k space, with spacing $2\pi/L$.

$$dN = 2\frac{4\pi K^2 dk}{(2\pi/L)^3} \qquad [1]$$

where the extra factor of two is due to the spin degeneracy of spin 1⁄2 electrons. The volume of the sample is L^3, so the carrier density is defined as $n=N/V=N/L^3$. Therefore density of states per unit volume in k -space is

$$\frac{dn}{dk} = g(k) = \frac{8\pi k^2}{(2\pi)^3} = \frac{k^2}{\pi^2} \qquad [2]$$

The 3D density of free states is

$$g_{3D} = \frac{k^2}{\pi^2} = \frac{m}{\hbar^2 k} = \frac{mk}{\pi^2 \hbar^2} = \frac{m}{\pi^2 \hbar^3}\sqrt{2mE} \quad [3]$$

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The above equation tells that the density of states in 3D is square root dependent on energy. It is known that the unconfined wave functions within 3D box are plane waves in all three dimensions.

In quantum wells, the electrons motion is confined into two dimensions and unconfined in the other dimensions; let assume its motion in the z-direction. Thus, the total energy of the system is the sum of the energy along the quantized direction and the energy along the other two directions [29].

Magnetic materials

In order to understand why semiconductors are traditionally not magnetic and how it is possible to introduce magnetic behavior in these materials is first necessary to look at the fundamental origins of magnetic behavior. And then analyze how magnetic behavior can be exploited in the development of dilute magnetic semiconductor compounds. Magnetism in materials arises from the fundamental property of electron spin, which is the intrinsic angular momentum of an electron.

Low dimensional diluted magnetism in Mn^{+2} doped $ZnTe$ semiconductors

One of the most useful aspects of semiconductors resides in their capacity to be doped with impurities, by which the electrical properties can be tuned. This approach has been developed to introduce magnetic ions into non-magnetic SCs to make them magnetic, known as DMS. The materials challenge is great because both magnetic and electronic doping is required, and the interaction between magnetic dopant spins and free carriers must be engineered to achieve thermally robust dopant spin carrier coupling. Magnetism and semiconducting properties are known to coexist in some ferromagnetic semiconductors, such as europium chalcogenides and ferrimagnetic or ferromagnetic semiconducting spinels. The first DMSs to be identified were II-VI semiconductor alloys like $Zn_{1-x}Mn_x Te$ and $\mathrm{Cd}_{1-x} Mn_x Te$.

RESULTS AND DISCUSSION

The reduced magnetization versus temperature can be computed by noting that each spin mode leads to one spin reversal distributed coherently throughout the entire lattice.

For better numerical estimations, we use the exchange integral of local magnetic moments $|J| \approx 1.602\times10^{-22}\ J$, the average lattice constant of $ZnTe$ a is 6.101Å used in the calculation, $S=5/2$ spin of Mn^{2+} and the Boltzman constant $K_B=1.38\times10^{-23}\ J/K$. And we use the magnetic ion impurity concentration range between $0<x<0.8$ in our case.

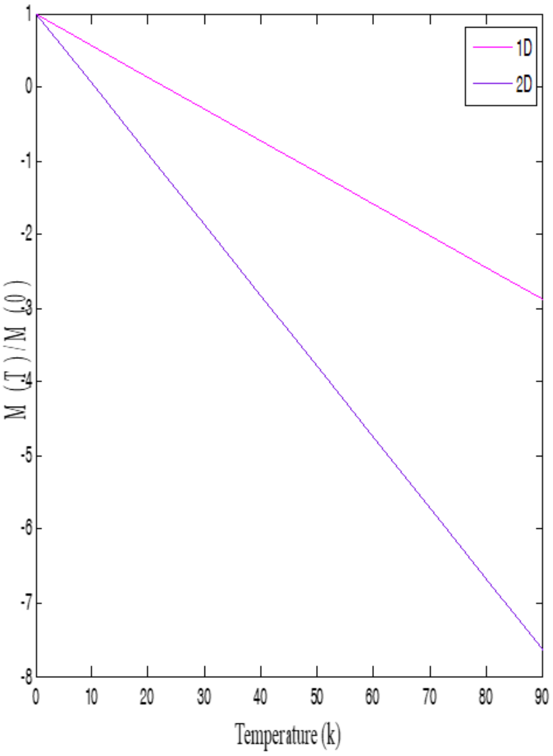

Figure 1: Reduced magnetization versus temperature in 2D and 1D.

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The aim in this subsection is to investigate the antiferromagnetic Heisenberg model spin system consisting of two interpenetrating sublattices and, which is described by the Hamiltonian

$$H = \sum_{ij} J(_{r_{ij}}) S_{ai}.S_{bj} - g\mu_B H_A \sum_i S^z_{ai} + g\mu_B H_A \sum_j S^z_{bj} \quad [4]$$

At first we express the spin rising and lowering sublattice operators with the help of creation-annihilation operators a_i^+ and a_i which have the following relations.

$$[a_i, a_j^+] = \delta_{ij} \ \ and \ [a_i, a_j] = [a_i^+, a_j^+] = 0 \quad [5]$$

dropping for the moment the subscript,

$$S_z^+|S_z\rangle = [S(S+1) - S_z(S_z+1)]^{\frac{1}{2}}|S_z+1\rangle \qquad [6]$$

$$= (S^2 + S + SS_z - SS_z - S_z^2 - S_z)^{\frac{1}{2}}|S_z+1\rangle \ [7]$$

$$= (S + S_z + 1)^{\frac{1}{2}}(S - S_z)^{\frac{1}{2}}|S_z+1\rangle \qquad [8]$$

$$S^+|S_z\rangle = (2S)^{\frac{1}{2}}\left(1 - \frac{S - S_z - 1}{2S}\right)^{\frac{1}{2}}(S - S_z)^{\frac{1}{2}}|S_z+1\rangle \qquad [9]$$

or, restricting the subscript i, we get, using (4)

$$S_i^+|n_i\rangle = (2S)^{\frac{1}{2}}\left(1 - \frac{n_i - 1}{2S}\right)^{\frac{1}{2}}(n_i)^{\frac{1}{2}}|n_i - 1\rangle \quad [10]$$

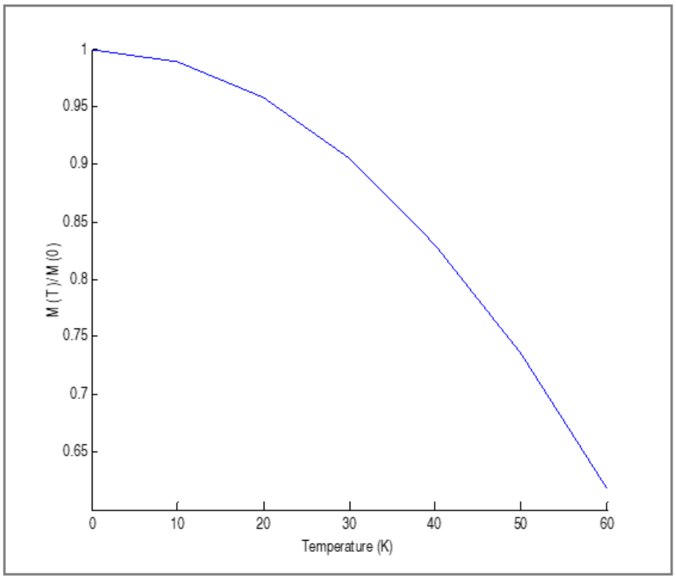

Figure 2: Reduced magnetization versus temperature in 3D

The concentration dependence of Neel temperature for Mn doped $ZnTe$ DMS in Eq. (9). Using spin wave theory an expression for transition temperature (Neel) as a function of concentration has been obtained asunstable, decomposes immediately and crystallizes in zincblende form. Zincblende structured $Zn_{1-x}Mn_xTe$ crystals have been grown conventionally by melt growth technique. Various methods of preparation of $Zn_{1-x}Mn_xTe$ in vertical and horizontal Bridgman methods have been reported .

As we have seen from the Figure the plot of Neel temperature versus manganese ion concentration is linear proportional to concentration x. It is reported in decreasing the Mn concentration, the critical temperature linearly decreases from 90 K at 100% occupation to 45 K at about 60%.

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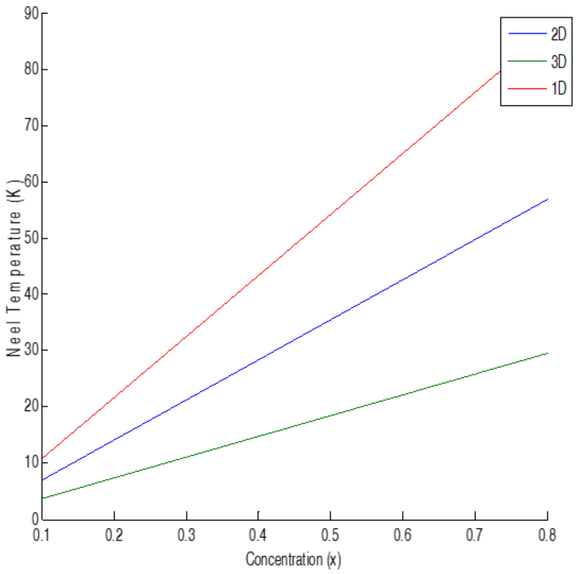

Figure 3: Neel temperature versus Mn^{2+} concentration in $1D$, $2D$ and $3D$.

As we have seen from the Figure the plot of Neel temperature versus manganese ion concentration is linear proportional to concentration x. It is reported in possible. This result matches with experimental values described in reference eel temperature for $Zn_{1-x}Mn_xTe$ increases when the concentration of manganese ion increases in the range given above). But in one dimensional and two dimensional structure the Neel temperature is greater than three dimensional bulk $Zn_{1-x}Mn_xTe$ in the same concentration range. This shows that low dimensional structure are applicable than bulk, because of they have highest Neel temperature.

In a few past decades, the hurriedly growing field of diluted magnetic semiconductors has attracted interest to their potential for spintronics devices mean that they have both semiconducting and magnetic properties which provide the possibility to manipulate electron charge and spin at the same time and opens a new field in semiconductor technology. DMSs are known by their special property like addition of magnetic impurities instead of few portions of compound semiconductors at cation sites. Advances in semiconductor materials technology has resulted in the development of a wide range of electronic and optoelectronic device structures with extremely small dimensions. Over the last decades the field of dilute magnetic semiconductors (DMS) has seen important developments both in fundamental aspects and prospective technological applications. From the point of view of prospective applications, the marriage between the world of low dimensional semiconductors.

CONCLUSION

This article is concluded as the impurity or the concentration is increased the temperature,the heat capacity and magnetization (magnetic property) of the diluted semiconductor is/are affected.In three dimensions, there is no confinement in the direction of motion of electrons. The only constrains is the periodic boundary conditions. The result matches with experimental values described for Neel temperature for $Zn_{1-x}Mn_xTe$ increases when the concentration of manganese ion increases in the given range. Diluted Magnetic Semiconductors are known by their special property like addition of magnetic impurities instead of few portions of compound semiconductors at cation sites. Advances in semiconductor materials technology has resulted in the development of a wide range of electronic and optoelectronic device structures with extremely small dimensions.

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