Benha University **Faculty of Science** **Department of Physics** **Ph.D (Graduate) Phy 710**	**First semester** **3 Jan. 2019** **Time of the exam: 1.5 hour** **January Test**

نصف ورقه امتحانيه

Advanced materials

Question 1

- Define the nanostructure and compare between it's different shapes.

10 Marks

- Proof that the density of phonon states in the Debye approximation depends on the dimensionality.

10 Marks

Question 2

- Give short note about the quantum dot laser, and Illustrate excitation and emission of light from vibrational energy levels that provide the basis of Raman spectroscopy.

10 Marks

- Give short note about nanosized MOSFETs.

10 Marks

Question 3

- Discuss theoretical predictions of nanostructured magnetic semiconductors.

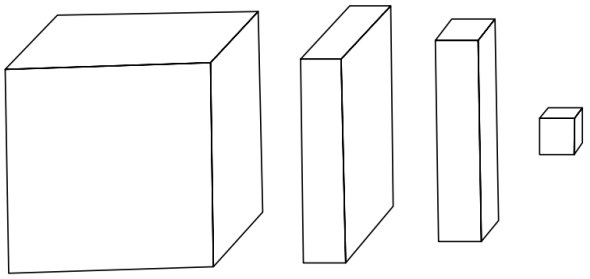
10 Marks

- Discuss the role and mechanism of spintronic material in memory devices.

10 Marks

Answer

Question 1



Nanostructures are generally considered to consist of a number of atoms or molecules bonded together in a cluster with at least one dimension less than 100nm. A nanometer is 10^{-9}m or 10Å. f one dimension is reduced to the nano range while the other two dimensions remain large, then we obtain a structure known as a well. If two dimensions are reduced, while one remains large, the resulting structure is referred to as a wire. The limiting case of this process of size reduction in which all three dimensions reach the low nanometer range is called a dot.

One approximation due to Debye assumes that the relationship is linear, which is valid for low values of k, that is,

$$\omega(k) = uk \tag{1.22}$$

From Equations 1.21 and 1.22,

$$D(\omega)d\omega = B\omega^2 d\omega \tag{1.23}$$

where B is a constant, and thus,

$$D(\omega) = B\omega^2 \tag{1.24}$$

In three dimensions, the total number of modes is $3N$, which means

$$\int_0^{\omega_d} D(\omega)d\omega = 3N \tag{1.25}$$

where ω_d is the highest frequency that can propagate in the lattice and is referred to as the Debye frequency. Thus, for three dimensions in the Debye approximation, the density of states for $\omega < \omega_d$ is

$$D(\omega) = \frac{9N\omega^2}{\omega_d^3} \tag{1.26}$$

In two dimensions, we would carry out the analogous derivation using a circle having area πK^2 obtaining

$$D(k)dk = 2\pi k dk \tag{1.27}$$

and

$$D(\omega)d\omega = \omega d\omega \tag{1.28}$$

$$\int_0^{\omega_d} D(\omega)d\omega = 2N \tag{1.29}$$

$$D(\omega) = \frac{4\omega N}{\omega_d^2} \tag{1.30}$$

Following the same procedure, the density of states in one dimension can be obtained to be

$$D(\omega) = \frac{N}{\omega_d} \tag{1.31}$$

Thus, the density of phonon states in the Debye approximation depends on the dimensionality of the material. Figure 1.16 shows a plot of phonon density of states versus the frequency for the different dimensions. Notice that the density of states decreases with the number of atoms N, which means the density of states will decrease in the nanometer range.

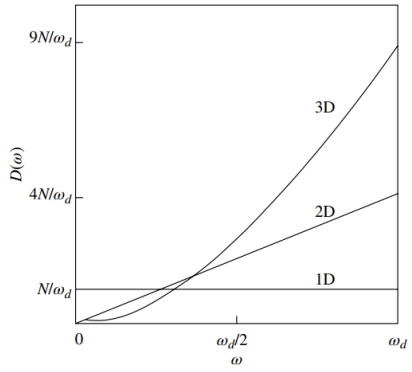


FIGURE 1.16 Density of phonon states versus frequency in the Debye approximation for one-, two-, and three-dimensional materials.

Question 2

Quantum dots such as the cubic dot, having energy levels given by the above equation, have been developed into one of the major applications of nanotechnology. The quantum dot laser is used in CD players to read the groves on the disk. The separation between the levels in the dot can be chosen by the value of *a* in Equation 1.12. There is a value of *a* in which the separation of the energy levels from the conduction band can be in the infrared (Ir) frequency range. This means an Ir photon can excite an electron to the conduction band and application of a voltage produces a current. This is the basis for the use of the quantum dot as an Ir detector. It is possible with appropriate excitation to produce a population inversion in the energy levels of the dot. This means that one of the upper levels has more electrons than a lower level, which is necessary to produce laser light. The constituents of a solid lattice vibrate. The specific frequencies, called the normal modes of vibration, are determined by the nature of the interaction between constituents of the lattice and the symmetry of the lattice. The vibrational frequencies of solids can be measured by Ir spectroscopy and raman spectroscopy. IR spectroscopy measures the absorption of Ir light when it induces a transition from the N=0 vibrational state to the N= 1 state. The basis of raman spectroscopy is illustrated in Figure 1.13. Laser light is used to excite the lowest energy level of a vibration to some higher level. The higher level excited state then decays back to the lowest level. However, some of decay goes to a vibrational state above the ground state. The frequency of this emitted light is measured, and the difference between the frequencies of exciting laser light and the emitted light measures the vibrational frequency. When solids are reduced to nanometer dimensions, the frequencies generally decrease. Figure 1.14 shows a plot of the decrease in the frequency of the longitudinal optical mode of silicon as a function of particle size measured by raman spectroscopy.

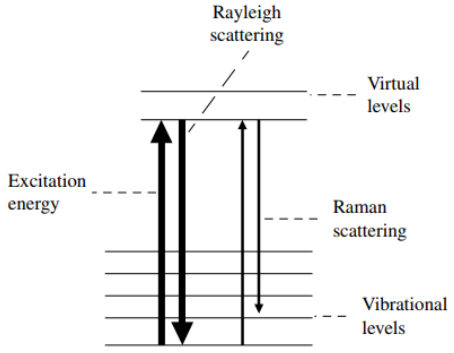


FIGURE 1.13 Illustration of excitation and emission of light from vibrational energy levels providing the basis of Raman spectroscopy.

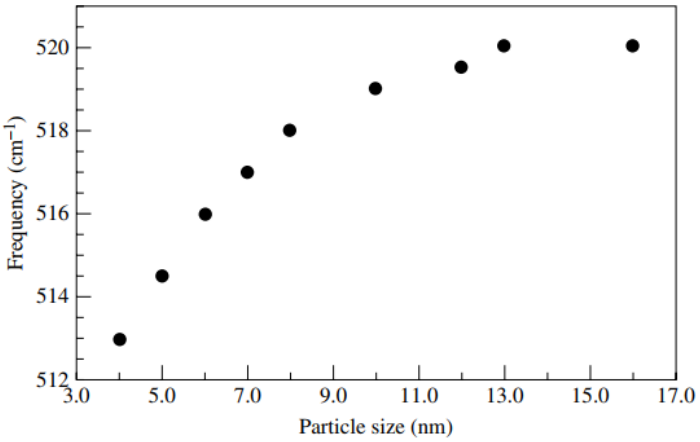


FIGURE 1.14 Plot of the frequency of the longitudinal optical mode of silicon versus the particle size measured by Raman spectroscopy. (Adapted from Ref. [7].)

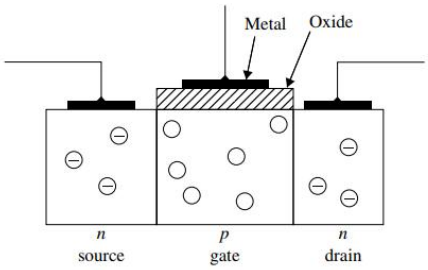


FIGURE 6.5 A schematic illustration of a metal–oxide–semiconductor field-effect transistor called a MOSFET.

Figure 6.5 shows a simple illustration of a MoSFeT, which consists of a P-type semiconductor with an N-type one on both sides. on the top of the P type is a thin layer of silicon oxide that has on top of it a thin layer of a metal connected to an electrical lead to which a voltage can be applied. There is also a metal electrical contact on top of each N-doped semiconductor. If a voltage is applied across the two N types in the figure, no current will flow because one N–P junction is always reversed biased no matter what the polarity of the voltage. Now, if a positive voltage is applied to the metallic contact on the P-doped material called the gate, the holes in the gate will be pushed down to the bottom of the gate, and there will be a narrow channel under the silicon oxide layers, which will be N doped, and thus, current can flow across the junction through this layer when a voltage is applied across the two outer N-doped semiconductors. The device will be in an on state in this case and an off state when no voltage is applied to the gate. MoSFeTs are approaching nanometer dimensions. The clock speed of chips has increased by about 29% a year since 1980 because methods have been developed to fabricate smaller and smaller switches on a chip.

Question 3

Theoretical modeling can also be used to determine the properties of existing materials and is particularly useful in predicting properties that are difficult to determine experimentally.

The research to develop magnetic semiconductors has primarily focused on doping existing semiconductors such as silicon or gallium phosphide with cu or Mn. However, other approaches have been proposed based on predictions from computational modeling. reducing an antiferromagnetic semiconductor to nanometer sizes could be an approach to producing a magnetic semiconductor. Semiconductors that have antiferromagnetic phases do exist. one example is copper oxide, which is a narrow band gap P-type semiconductor. It undergoes a transition to an antiferromagnetic state at 230K. It has been shown that when cuo is reduced to sizes below 10nm it displays ferromagnetism. Another example of predicting ferromagnetism in semiconducting materials involves boron nitride nanoribbons. Figure 6.18 shows a plot of the calculated HoMo–LUMo energy gap versus ribbon length of a zigzag boron nitride nanoribbon similar to the graphene shown in Figure 5.17a [15]. The calculation used dFT with the local spin density approximation employing periodic boundary conditions. The results show that at the longer lengths the ribbon becomes semiconducting. Interestingly, the calculation for an armchair ribbon did not show such a decrease with increasing ribbon length. It was shown that when a carbon atom replaced nitrogen, the ribbon was semiconducting and had a larger density of states for the spin down state at the Fermi level. These results suggest that carbon-doped boron nitride nanoribbons could be ferromagnetic semiconductors. Neither of these two results has been experimentally verified; however, the predictions suggest materials to focus synthesis on.

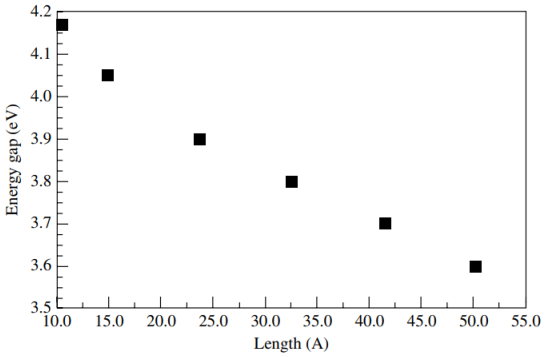


FIGURE 6.18 Calculated band gap of zigzag BN nanoribbons versus ribbon length (Adapted from Ref. [15]).

pintronics also known as magneto electronics,is an emerging technology that exploits both the intrinsic spin of the electron and its associated magnetic moment, in addition to its fundamental electronic charge, in solid-state devices. Spintronics emerged from discoveries in the 1980s concerning spin-dependent electron transport phenomena in solid-state devices. This includes the observation of spin-polarized electron injection from a ferromagnetic metal to a normal metal(1985),and the discovery of giant magneto resistance(1988). The origins of spintronics can be traced back even further to the ferromagnet/superconductor tunneling xperiments, and initial experiments on magnetic tunnel junctions. The use of semiconductors for spintronics can be traced back at least as far as the theoretical proposal of a spin field-effect-transistor by Datta and Das in 1990. Recently integrated magnetic/spintronic device micro arrays have demonstrated great potentials in both biomedical research and practices. Also they have been widely used in creation of Magnetoresistive Random Access Memories. Motorola has developed a 1st generation 256 Kb MRAM based on a single magnetic tunnel junction and a single transistor and which has a read/write cycle of under 50 nanoseconds. The IBM-Infineon MRAM Development Alliance has recently developed a prototype 16Mb MRAM. Thermal Assisted Switching (TAS) which is being developed by Crocus Technology, and Spin Torque Transfer (STT) on which Crocus, Hynix, IBM, and several other companies are working. Another design in development, called Racetrack memory, encodes information in the direction of magnetization between domain walls of a ferromagnetic metal wire. The Seminar Spintronics and Spintronic devices will give an introduction on pintronics and will deal with the recent advances of spintronic devices like the MRAM, and will make a comparison of the other memories available at present and the advantage of the MRAM and its technical feasibility, the seminar will also cover spintronic logic devices and spintronic Devices in Magnetic BioSensing.