بررسی اثرات فشار بر خصوصیات پلاسمون سطحی

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چکیده - خصوصیات انتشاری و تلفاتی پلاسمون سحطی در فصل مشترک فلز – دی الکتریک تحت حضور فشار مطالعه شده و نشان داده می شود که در جامدات نیمه هادی و جامدات یونی به عنوان دی الکتریک و در فلزات چگونه تغییرات فشار موجب تغییر ثابت انتشار پلاسمون سطحی در فصل مشترک فلز - عایق در حوزه اپتیکی می گردد. همچنین ماهیت فیزیکی تغییرات ثابت دی الکتریکی جامدات در اثر فشار با تغییرات میزان قطبش پذیری جامد و ساختار باندی جامد فلزی به همراه روابط تئوری شرح داده می شود.

کلید واژه- اثرات فشار، قطبش پذیری جامدات، پلاسمون سطحی، ثابت دی الکتریک جامدات.

Investigating the effects of pressure on the surface Plasmon characteristics

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Abstract- This study investigates the propagation and losses characteristics of the surface Plasmon at the interface of metal-dielectric while exposure to the pressure and shows how the changes in the pressure lead to the propagation constant change in the interface of metal-insulator in the optical range in the semiconductor and ionic solids as dielectric and in the metals. Also, the physical nature of dielectric constant changes of the solids in the pressure by the changes of polarization of the solid and band-structure of solid and metal are explained. Also, the theoretical relations applied in this study are stated here.

Keywords: Effects of pressure, Polarization of the solids, Surface Plasmon, Dielectric constant of solid

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1 Introduction

Because of their advantages such as overcoming the limitations of diffraction and usage in the integration in the sub-wavelengths dimension in the optical range, the importance of the study of the surface Plasmon in the heterogeneous structures is clear to everybody [1]. Also, the relatedness of the surface Plasmon characteristics to the dielectric constant in the interface of the metal-insulator is discussed in different articles.[2-4] It is known that the dielectric constant of different materials do not show the same reaction under pressure. As an example, in the fluids, the effects of the pressure lead to a significant change in the density of the materials and decrease in the volume of materials increase in the bipolar in the volume and therefore increase in the dielectric constant. However, in the solids, by increasing the pressure, the change in the volume is insignificant [5]. Therefore, the changes in the insulator characteristics of the solids can be related to other factors such as the changes in the polarization as the microscopic parameter and the ability of the polarization of the crystal lattice of the solid and also to the changes of the internal fields and the prevalence of the repulsion effects. However, the changes in the pressure in ionic, non-ionic, and metal solids are not the same and physical nature of these changes is different. Also, the dielectric constant of different solids in different optical frequencies and lower frequencies does not show the same reaction. In optical frequencies, the dielectric features of the solids are caused by the significant changes in the short-range fields and these effects lead to the reduction of the polarization of the electron cloud under pressure. However, in lower frequencies the effects of the polarization of the network which was caused by the changes in the places of the positive and negative ions have more effects in the changes of the dielectric constant of the solids [6]. Bretscher figured out that the changes in the dielectric constant of the ionic solids are mostly by the polarization feature of the ionic network. He also stated that because of the changes in the bouncing forces between ions, these changes are severely affected by the pressure of the dielectric constant. The previously conducted experimental studies were mostly related to the low frequency features of the fluids and some frequently used solids such as polymers and are divided to the study of density, polarization, changes in the volume and elasticity coefficient of the materials which are mostly in the area of chemistry-physics and fluid mechanics [7]. Here, we intend to study the effects of pressure on the dielectric constant of the solids which compose the interfaces and emissive features of the waves in the interface of metal-dielectric which is used in the optical range. Hence, the anisotropy effects are neglected and the investigated materials are considered as isotropic and with the geometric structure of simple cube which feel the same pressure in all aspects. In the second section, the theory and formulation of the optical constant changes in solids, due to increasing of pressure have been presented. In the third section, the dielectric features of the ionic, semiconductor, and metal solids are discussed by considering the effects of pressure in the optical range and the effects of the pressure on the surface waves in the interface of metal-insulator are investigated which is composed of dispersion characteristics. Finally, discussion and conclusion have been reported.

2 Theoretical and formulation

Generally speaking, increase in the amount of pressure in different situations leads to a reduction in size; however, the amount of reduction in size is not the same in different situations. The increase in the pressure in ionic and semiconductor solids will lead to the decrease in the dielectric constant of the solid material. Hence, the insulator solid materials which are under investigation in this study are ionic and semiconductor solids which their anisotropy features are ignored. The decrease in the dielectric constant which is because of the increase in the pressure has a frequency dependence nature and in different frequencies, has different changes. The theoretical relations to describe the insulating features of ionic crystals can be justified by Mott and Littleton’s theory [8]. In optical range, the polarization capacity of the ionic network is usually minute and the effects of local fields which are caused by the effect of microscopic and polarizing fields will be calculated by $E_{eff} = E + P/3\varepsilon_0$ [9]. In this case, Mott and Littleton theory be used as the equation (1) in optical frequencies which is known as Clausius-Mossotti equation [10].

$$\frac{\varepsilon-1}{\varepsilon+2} = \frac{\alpha}{3\varepsilon_0 \nu} \quad (1)$$

In which α is the polarization capacity of the electron cloud in ions and ν is the volume of the intended material. In this case, the relatedness of the pressure to the dielectric constant of the material will be calculated with equation (2):

$$\frac{1}{(\varepsilon-1)(\varepsilon+2)} \cdot \left(\frac{\partial \varepsilon}{\partial p}\right) = -\frac{1}{3\nu} \cdot \left(\frac{\partial \nu}{\partial p}\right) + \frac{1}{3\alpha}\left(\frac{\partial \alpha}{\partial \nu}\right) \cdot \left(\frac{\partial \nu}{\partial p}\right) \quad (2)$$

For the external ions in semiconductor solids, it is stimulated in both cases and the base of wave function is increased and therefore, the total effects the microscopic and polarizer fields is approximately equal to the effects of the average of the microscopic fields[8] and it can approximately be stated that $E_{eff} \approx E$. And therefore, equation (1) can be revised as the equation (3).

$$\varepsilon - 1 = \frac{\alpha}{3\varepsilon_0 \nu} \quad (3)$$

Hence, the changes in the dielectric constant of the semiconductor solid which is dependent to the pressure can be written as the equation (4).

$$\frac{\varepsilon}{(\varepsilon-1)} \cdot \left(\frac{\partial ln\varepsilon}{\partial p}\right) = -\left(\frac{\partial ln\nu}{\partial p}\right) + \left(\frac{\partial ln\alpha}{\partial ln\nu}\right) \cdot \left(\frac{\partial ln\nu}{\partial p}\right) \quad (4)$$

As shown in the equations (2) and (4), the changes in the dielectric constant in the solid material by the pressure are due to two factors: 1, the effects of pressure which lead to the changes in the density of the material and therefore lead to the positive increase in the dielectric constant, 2, the effects which lead to the changes in the polarization capabilities of the material with the changes in the volume by increase in the pressure. It is clear that with the decrease in the volume of the solid material, the polarization capacity of the electron cloud will decrease and therefore, the decrease in the polarization will lead to the decrease in the dielectric constant. Table (1) shows the dependence of the dielectric constant of the semiconductor solids with the changes of the changes of the pressure compared to the ionic solids.

Table 1: dielectric constant of solid and dielectric constant dependence on pressure [9,11]

Material	$(\partial\varepsilon/\partial p) \times 10^5 (Bar^{-1})$	*Dielectric constant* (ε_∞)
ZnS	-0.1352	5.20
CdS(c)	-0.5918	5.38
C	-0.06281	5.71
Ge	-5.44	16.00
LiF a	-4.0788	9.27
NaCl a	-5.58628	5.62
KCl I	-4.68	4.68

3 Result

Figure (1) shows the changes in the dielectric constant by the changes in the pressure for the solid materials in the room temperature. Also, it was shown that the dielectric constant changes for the solids have significant decrease but for the ionic solids, these changes are more rapid and significant. The changes in the dielectric constant under pressure up to 8 KBar for Sodium Chloride is the highest and for Carbon is the lowest.

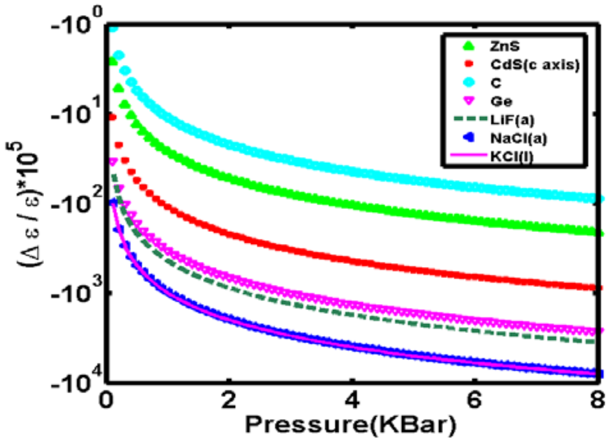

Figure 1: the changes in the dielectric constant of the ionic and semiconductor solids under pressure

The compression capacity of the volume under pressure for noble metals cannot be ignored compared to the insulators. Also, the effects of pressure in the noble metals are usually studied in the form of the change such as the band structure in the range of optical frequencies. The highest effect of the band changes occurs in the range of the cut off frequency for the metals in which the measurement for the reflection spectrum in the room temperature shows the changes of 4.10 GHz/Bar for the frequency of minimum reflection in the element of silver and 1.52 GHz/Bar for copper and gold[12]. If Drude's model used to describe the dispersive characteristics of noble metal of 1470 nanometer wavelength, by increasing the pressure up to 10 KB for the silver and gold metals, the real part will experience a change from 0.9-1.85 and 0.69-1.16, respectively and these changes will be 11.45-11.77 and 9.664-9.684 for the imaginary part, respectively and these changes are more for the silver than gold.

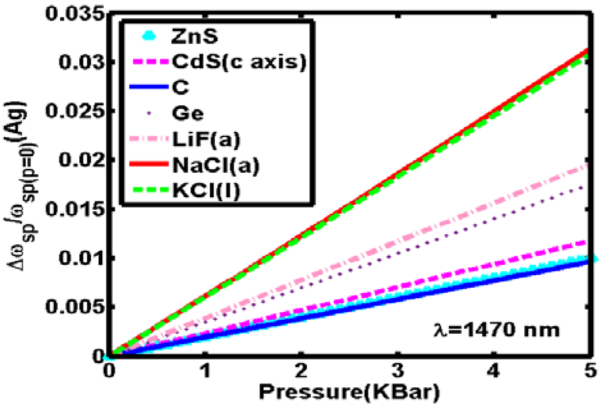

Figure 2: surface Plasmon frequency as a function of pressure

As shown in Figure (2), the sensitivity of the frequency of the surface Plasmon to the pressure has the maximum changes for the interface of the silver and the dielectric of the Sodium Chloride and the minimum changes for Carbon.

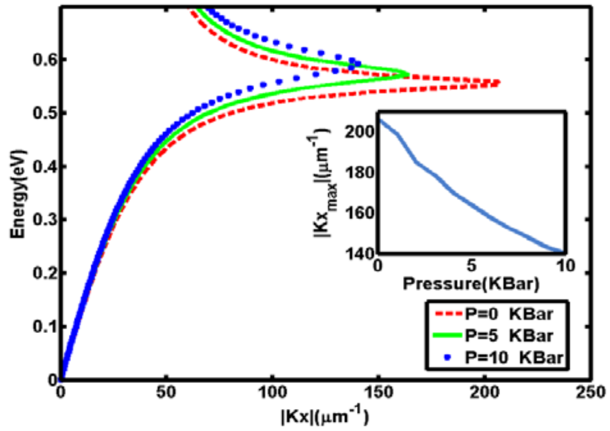

Figure 3: surface plasmon dispersion curves for transverse magnetic wave as a function of pressure And inset maximum propagation constant changes for pressure

Figure (3) show the changes in the dispersion curve for transverse magnetic wave mode with the pressure of 5 to 10 KBar compared to the dispersion curve without considering the effects of pressure. By the increase in the pressure, the dispersion curve show a transfer to the higher energies for the interface of the silver and Sodium Chloride. The inset of figure (3) illustrates that by increasing the effects of pressure, the maximum of the propagation constant of the surface Plasmon shows a declining trend.

4 Conclusion

Generally, increase of the pressure in the ionic and semiconductor solids leads to the decrease in the dielectric constant in which the declining trend for the ionic solids will be more than semiconductor ones. The reason for these changes is to overcome the effects of decrease in the polarization capacity in the volume and the effects of increase of density in the dielectric constant of the solids. The changes in the band structure of the solids under the influence of the changes in the pressure make great changes in the dispersive dielectric constant of the metals in the cut-off frequency range.

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