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Filtering Properties of EPSCM for High Value of K and Radius of Spherical EPSCM

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Abstract

Direct measurements of the functional dependencies of the electric resistivity and the molar volume on enthalpy and pressure have been performed for graphite and liquid carbon. It has been found that for graphite at the pressures $P \leq 1$ GPa the isochoric temperature coefficient of resistance is positive, while for liquid carbon it is negative over the entire pressure range investigated where $P = 0.5–3.5$ GPa. These observations probably indicate that graphite is a metal whereas liquid carbon is not a metal, so that the melting of graphite under such pressures coincides with a metal-to-nonmetal transition. The authors have interest to study Filtering properties of EPSCM for high value of K and radius of spherical EPSCM by refractive index of materials

Keywords: Plasmon, Phonon, Polaritons, Hydrodynamical Model

Introduction

Graphite is a unique high-temperature structural material because of its high melting temperature and the relatively low values of the viscosity coefficient and density. This material is used, in particular, for the construction of nuclear reactors and supersonic aircraft. Since under certain conditions graphite melts, in order to estimate the mechanical and thermal stability of the constructions the data on the thermo physical properties of liquid carbon are also needed. These data may be required as well for the optimization of such processes as the growth of diamond from graphite, the fabrication of amorphous carbon and the laser processing of graphite. Knowledge of thermo physical properties of liquid carbon is necessary for constructing the phase diagram of carbon, which is of crucial importance for the understanding of different physical phenomena in geophysics and astronomy [1, 2]. However, direct measurements of the properties under controlled conditions have not yet been made.

It should be noted that the thermo physical properties of carbon in wide ranges of temperature and pressure have been extensively investigated by means of the molecular dynamics simulations using *ab initio* techniques [3, 4] as well as empirical inter atomic potentials [5]. The results obtained in these studies are not quite consistent with each other and are considerably dependent on the method of description of the electronic properties. Bundy [6] investigated the behavior of the electrical resistance of graphite specimens placed in high-pressure apparatus and heated by an electric current pulse. He measured the dependence of the resistance on the quantity of heat generated by the current pulse in the specimens and determined the heat of fusion of graphite at different pressures. This was done by analyzing the crystal structure of the specimens after the experiments. Since the crystal structure of graphite formed during the recrystallization of liquid carbon differed remarkably from the original structure of graphite, it was possible to determine which part of the specimen had melted. However, Bundy did not control the change in the specimen volume so he could only estimate quantities such as resistivity and enthalpy.

The same approach was used later by Togaya [7] who made an attempt to find out whether liquid carbon is a metal or not. He came to the conclusion that at pressures below 4 ε GPa liquid carbon is a poorly conductive metal since its resistance at these pressures increases with the increase in the quantity of heat generated in it. Korobenko *et al* [8] measured the dependence of the temperature of the graphite specimens on the amount of heat generated in them by the passage of an electric current pulse. The specimens in the work [8] were made of highly oriented pyrolytic graphite (HOPG). Some of the specimens had the form of thin

plates sandwiched between two thick glass plates. On melting the specimens, slightly sloping temperature plateaus in the range of temperature values from 5000 to 6000 ε K were observed [8]. The determined values of specific enthalpy at the beginning and end of the melting plateaus agreed well with those obtained by Bundy [6]. It has also been shown [8] that in the dependence of the resistance of a specimen on the quantity of heat generated in it, there are two singularities (kinks) situated at the beginning and end of the temperature plateau. However, neither pressure nor volume was measured in [7,8] and consequently enthalpy and resistivity were determined with an error which exceeded 20%.

. To perform the measurements it is use the nanosecond resolution pulse-heating technique [9, 10]. A specimen of HOPG in the form of a rectangular parallelepiped (a thin strip) is placed between two polished-to-optical-quality thick plates of the window material used in the high-pressure investigations as described in [11]. The graphite hexagonal axis *c* is directed perpendicular to the surface of the strip. The assembly is carefully glued. The specimen ends are covered with copper and in the experiment are pressed to flat massive electrodes to ensure good electrical contact and appropriate boundary conditions for the thermal expansion of the specimen. Heating of the specimen is accomplished by a current pulse with a magnitude of 12–18 kA and a rise time of about 0.6 μs. It was demonstrated earlier that under such conditions the specimen can be sufficiently homogeneously heated and its thermal expansion is nearly 1D [12]. In these experiments, the specimen is heated to temperature values in the order of 10^4 K so that intensive thermal conduction heat fluxes from the hot specimen to the sapphire plates arise. Consequently, the temperature in the sapphire layers adjoining the hot specimen increases appreciably. The thickness of such a layer δ is in the order of $\sqrt{\chi t}$, where χ is the thermal diffusivity of sapphire and t is the time of heating. It is assumed here that the sapphire plate has a good thermal contact with the specimen. For the typical time of the measurements $t \sim 1$ μs and $\chi \sim 10^{-2}$ cm^2 s^{-1}, which is the thermal diffusivity of sapphire at $T \approx 1000$ K, we obtain $\delta \sim 1$ μm. This value is much smaller than the thickness of the specimen, which due to the thermal expansion reaches the values of the order of 100 μm. Actually, in their experiments between the specimen and the sapphire plates there is a layer of 1–3 μm thickness of the glue used to bound the experimental assembly so that the losses are even less since the thermal diffusivity of the glue is essentially smaller than that of sapphire [10]. The thickness of the layer heated to high temperatures in the metallic electrodes delivering the current to the specimen is three to five times larger than that in the sapphire plates, but this quantity is negligibly small in comparison with the specimen length (~1 cm). This is the reason it is neglected, in these measurements, the heat losses due to heat conduction [13, 14].

Theoretical Study

The spherical polar semiconductor particle is considered to be embedded in a non-dispersive bounding dielectric medium characterized by the dielectric constant ε (kω).

The surface of the polar semiconductor particle supported TM surface polariton waves.The Bloch's Hydrodynamical equations may be employed for the case of spherical interface, by obtaining their solutions in spherical co-ordinates (r,θ,$\emptyset$).These equations are as follows :-

$$\left(\beta^2\nabla^2+\omega^2-\omega_p^2\right)\overline{\nabla}.\overline{E}=0 \text{ and}$$

$$\left(c^2\nabla^2+\varepsilon_L\omega^2=\bar{\varepsilon}\omega_p^2\right)\overline{\nabla}x\overline{E}=0$$

The time and position dependence of the electromagnetic field is written as exp. ($i\bar{k}.\bar{r}-i\omega t$). The above equations may be written as-

$$\left[\nabla^2-\gamma^2\right]\overline{\nabla}.\overline{E}=0 \qquad (1)$$

and $$\left[\nabla^2-\alpha^2\right]\overline{\nabla}\ x\ \overline{E}=0 \qquad (2)$$

Where $$\gamma^2=\frac{\omega_p^2-\omega^2}{\beta^2} \qquad (3)$$

and $$\alpha^2=\frac{-\varepsilon_L(k\omega)\omega^2+\bar{\varepsilon}(k\omega)\omega_p^2}{C^2} \qquad (4)$$

The solution of equation (1) and equation (2) can be written in terms of scalar potential functions φ_γ and φ_α as

$$\overline{E^\gamma}=\overline{\nabla}\psi_\gamma \qquad (5)$$

$$\overline{E}_1^\alpha=\overline{\nabla}\times\left(\hat{r}\bar{r}\psi_\gamma\right) \qquad (6)$$

$$\overline{E}_2^\alpha=\frac{1}{\alpha}\overline{\nabla}\times\left(\overline{E^\alpha}\right) \qquad (7)$$

Where r is the radius of sphere and $\hat{r}$ the unit vector along r.the scaler potential functions φ_γ *and* φ_α can be expanded in terms of spherical harmonics as-

$$\psi_\gamma=\sum_{lm}\psi_{\gamma l}(\bar{r})\gamma_l^m(\theta\phi)e^{i\bar{k}.\bar{r}} \qquad (8)$$

and $$\psi_\alpha=\sum_{lm}\psi_{\gamma l}(r)\gamma_l^m(\theta\phi)e^{ik.r} \qquad (9)$$

where l, m are integers.

The operator ∇^2, is called laplacian equation is written in spherical co –ordinate as -

$$\nabla^2=\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial}{\partial r^2}\right)+\frac{1}{r^2\sin\theta\partial\theta}\left(\sin\theta\frac{\partial}{\partial\theta}\right)+\frac{1}{\sin^2\theta}\frac{\partial^2}{\partial\phi^2} \qquad (10)$$

For the spherical polar semiconductor the equilibrium electronic function$\varphi_{rl}(r)$ must satisfy the following conditions-

$$\psi_{\gamma 0}.(\bar{r})=\psi_0 \qquad \text{for<R} \quad =0 \qquad (11)$$

$$\text{for r>R} \qquad (12)$$

Now using equations (8) and (10) in equation (1), we get

$$\left[\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial}{\partial r}\right)+\frac{1}{r^2\sin\theta}\left(\sin\theta\frac{\partial}{\partial\theta}\right)+\frac{1}{r^2\sin\theta}\frac{\partial^2}{2\phi^2}-\gamma^2\right]\times$$

$$\psi_{\gamma^1}(\bar{r})\gamma_l^m(\theta\phi)e^{i\bar{k}.\bar{r}}=0 \qquad (13)$$

From equation (13) is a partial differential equation of second order and it may be solved by the method of separation of variables in order to separate the variables.The dispersion relation for surface plasma, Polaritons and phonons including spatial dispersion effect as given -

$$RX_i'(ykR)\left(\frac{\varepsilon_\infty(k\omega)\Omega^2-\varepsilon_0(k\omega)\frac{\omega_t^2}{\omega_p^2}}{\Omega^2-\frac{\omega_t^2}{\omega_p^2}}\right)\left[\left\{\bar{\varepsilon}(kw)-\left(\frac{\varepsilon_\infty(k\omega)\Omega^2-\varepsilon_0(k\omega)0\frac{\omega_t^2}{\omega_p^2}}{\Omega^2-\frac{\omega_t^2}{\omega_p^2}}\right)\Omega^2/RZ(\partial kR/\right\}$$

$$(X(\gamma kR))Y(\alpha kR)+\varepsilon_B(k\omega)\Omega^2(RX(\gamma kR))'Z(\delta kR)\Big]$$

$$-1(1+1)X(\gamma kR)Y(\alpha kR)Z(\partial kR)\varepsilon_B(k\omega)\bar{\varepsilon}(k\omega)=0 \quad (14)$$

Further study of the dispersion relation for surface Plasmon, Phonon,Polariton, for non-spatially dispersion case, from eq. (14) by taking the limit γR→∞ and ξ→0, then eq. (14) become in a new form-

$$\Omega^2\left(\frac{\omega_p}{\omega_t}\right)^2\varepsilon_\infty-\left[\varepsilon_0+\left\{\bar{\varepsilon}-(1+\varepsilon_\infty)k^2\right\}\left(\frac{\omega_p}{\omega_t}\right)^2\right]\Omega^4$$

$$+\left[\left\{(1+\varepsilon_0)+\bar{\varepsilon}\left(\frac{\omega_p}{\omega_t}\right)^2\right\}k^2+\bar{\varepsilon}\right]\Omega^2-\bar{\varepsilon}k^2=0 \quad (15)$$

The equation (15) can be also modified in terms of refractive index 'n'

$$n^2=\left[\frac{\Omega^2(12.3\Omega^2-(11)-13.6(\Omega^2-0.74))}{(\Omega^2-0.74)(\Omega^2-13.6)-\Omega^2(12.3\Omega^2-(11))}\right] \quad (16)$$

Sl. No.	Ω^2	n^2	ε(Ω)
1	0	1	-∞
2	0.1	1.008	-120
3	0.2	1.019	-52.18
4	0.3	1.036	-28.71
5	0.4	1.066	-16.11
6	0.5	1.166	-6.99
7	0.6	-0.65	-0.39
8	0.7	0.76	0.39
9	0.8	0.975	40.32
10	0.9	1.028	-36.33
11	1	1.07	-14.67
12	1.1	1.13	-8.6
13	1.2	1.23	-5.33
14	1.3	1.46	-3.15
15	1.4	2.81	-1.55
16	1.5	-0.408	-0.29
17	1.6	0.423	0.73
18	1.7	0.61	1.59
19	1.8	0.699	2.32
20	1.9	0.747	2.95
21	2	0.786	3.5
22	2.1	0.799	3.99

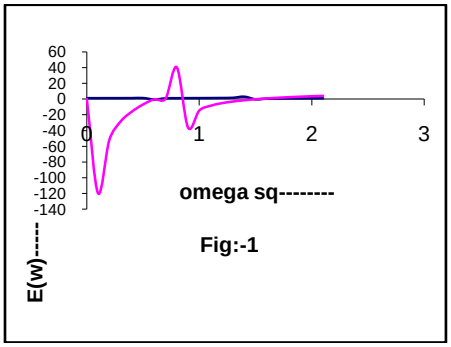

Fig:-1

Conclusion

When, we observe the fig. (1) we find that there are two discontinuities at the two values of frequencies ($\Omega^2=0.56\ and\ 1.34$) i.e. (Ω=0.75 and Ω=1.16) in the plot of n^2 tends to ∞.The frequency values of the incident EM radiation match exactly with the coupled SP-SOP mode frequencies, leading to strong coupling which results in surface plasmon, phonon polariton modes. Thus at these points, there is a strong resonance between the incident EM wave and strong coupled SP-SOP excitation modes. Therefore at these values of frequency of the incident EM wave, no light is transmitted through the medium; the whole energy propagates as bound surface polariton wave along the interface. It is clear that the value of ε (Ω) is (-0.1), which is the condition of existence of bound, non-radiative surface mode.

The value of n^2 is remains negative in the narrow range between $\Omega^2=0.56$ and 0.58, and again$\Omega^2=1.42$. Thus for these two ranges of frequency of index of refraction of the medium, become imaginary this indicates that incident EM waves of these frequency range will be totally reflected. Thus n^2>1,values correspond to the non radiative. For n^2<1, ε (Ω) is positive. This occurs for the frequency range between $\Omega^2=0.58$ and 0.74 and then square of Ω> 1.42, thus for these values of frequency the condition for radiative Brewster surface mode is satisfied. The values of n^2 become zero at two points for $\Omega^2=0.58$ and for 1.42. Thus the surface wave can be transferred to the bulk of the medium. In other words, at these frequencies the condition for perfect transmission of incident EM wave is satisfied.

The incident radiation is not transmitted through the active medium for those ranges of frequencies for which the surface modes are bound and non radiative. For those values of frequency for which the surface mode become radiative, the incident energy can be filtered or transmitted through the medium. It is clear that for Ω=0.76 and for 0.848 the medium become transparent to the incident radiation in this range. Above these frequency range between Ω=0.848 and Ω=1.119, the surface modes become non radiative so that the medium become opaque, for the incident EM radiation. For Ω>1.119 and higher values the surface again become transparent. Thus the surface of polar semiconductor acts as a high pass and band pass filter for incident EM waves.

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