MECHANOLUMINESCENCE PRODUCED DURING CLEAVAGE OF ELEMENTAL SEMICONDUCTORS

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Abstract

Mechanoluminescence is a type of luminescence produced during any mechanical action on solids like grinding, rubbing, cutting, cleaving, shaking,scratching, compressing or by crushing of solids. The phenomenon of mechanoluminescence (ML) is known for a long time. The physical processes involved in inducing ML in solids, as deformation ML and tribo ML. The ML has been observed in a large number of organic, inorganic, crystalline, non-crystalline materials, insulators, semiconductors as well as in conductors.The energy of emitted photons increases with the band gap of materials and both the n-type and p-type semiconductors of the same material exhibit similar spectra. The emission occurs in at least in two wavelength regions and above 1 eV energy and the other between 0.25 and 0.36 eV. Intensities for about 0.1 cm2. Cleaved areas are in the region of 1012 photons in region A and 1011 photons in region B. ML has many potentially important applications. It provides a self-indicating method of monitoring the microscopic and macroscopic processes occurring during deformation and fracture of solids.

Keywords: Semiconductors, Mechano luminescence, Cleavage.

I. INTRODUCTION

The ML of elemental and III-V semiconductors was first reported by Jenny (1957). He has found that the energy of emitted photons increases with the band gap of materials and both the n-type and p-type semiconductors of the same material exhibit similar spectra. Li et al (1993) have studied the cleavage luminescence from GaAs and InP as well as from Si in high vacuum. A new Si signal has been found, tentatively ascribed to surface defect. Unlike Si, the III-V materials also show luminescence from cleavage in air. Li et al (1994) have reported the cleavage luminescence from InP, Ge and three different compositions of Ge_xSi_{1-x}. They have found that all compounds have common characteristic in that there are at least two type of emission in different wavelength regions. One type appears from cleavage in vacuum only and has relatively long durations in the cases of the elemental semiconductors. The origin of luminescence is recombination of cleavage-excited electrons across the bulk band gap. The other type of luminescence appears also in air and has short (20 μs or less) durations for all of the materials. This radiation is ascribed to recombination at surface defect, including vacancies.

II.MECHANISMOFMLINELEMENTALA NDIII-V SEMICONDUCTORS

For the ML excitation in elemental and III-V semiconductors, the following models may be proposed:

(i) <u>Charging of newly created surfaces:</u>

The possibility of charging of newly created surfaces due to the movement of charged dislocations. At the core of a dislocationin a semiconductors such as Ge or Si there are electrons states associated with dangling bonds, and these may act as donors or as acceptors. The properties of these charged dislocation have been studied both theoretically and experimentally. No electrical effects of the movements of dislocation ina semiconductors like Ge, Si, InP and GaAs can be detected, because the screening charge moves with the dislocation very easily. Thus, the ML model involving surface charging of newly created

surfaces may not provide a dominating process for the ML in elemental and III-V semiconductors.

(ii) Thermal Generation Of Charge Carriers:

Thermal generation of electron-hole pairs by excitation across the band gap would require temperature in excess of 700 K to produce the observed electronic transitions. Since GaAs is a direct band gap semiconductors, and it has low value of thermal conductivity, it should show more ML as compared to Ge and Si which are indirect band semiconductors and have comparatively high value of thermal conductivity. Practically Ge and Si show high ML as compared to GaAs. Therfore, the model involving thermal generation of charge carriers may not provide a dominating process for the ML produced during fracture of elemental and III-V semiconductor.

(iii) Recombination Of Fracture-Generated Defects:

Other energetic processes occur on fracture surfaces including the production of defects such as vacancies and atoms. The recombination of fracture generated defects is slow process, and if this model is responsible, the ML should appear for a significant time after the cleavage of semiconductors. But it has been found that the ML in semiconductors disappears very rapidly after their fracture. Thus, the ML model involving recombination of fracture- generated defects may not be a dominating process in elemental and III-V semiconductors.

(iv) Formation Of Crack-Induced Localized States:

The radiative recombination of electron and holes may give rise to mechanoluminescence. Electronic excitations resulting in charge carrier production would likely be associated with localized states of energy greater than or equal to that of the conduction band. The total number of photons produced during the creation of unit surface area are $3X10^8$, $1.52X10^{10}$, $7X10^6$ and $3X10^4$ for Ge, Si, InP and GaAs semiconductors, respectively. The band gaps of Ge, Si, InP and GaAs are 0.67,1.14,1.35 and 1.43 eV, respectively. It follows that the number of photons emitted decreases with increasing energy of the band gap. This fact support the ML model involving formation of crack-induced localized states.

III. THEORY

Linke have measured the time-resolved crack velocity during the cleavage of alkali halide crystals. They have shown that initially the crack moves at low velocity, but very soon it attains a fixed velocity after attaining a certain crack length. If a crystal having length L, breadth W and thickness H is cleaved along the plane parallel to creation of new surfaces is given by 2Wv, where vis the average velocity of cleavage plane or the velocity of crack propagation. If B is the number of free charge carriers produced during the creation of unit surface area, then the rate of generation of the charge carriers

$g = 2BWv$ (1)

In intrinsic semiconductors the number of electrons is equal to number of holes. In this case, luminescence is produced during the radiative recombination of holes and electrons. If α_1 and α_2 are the recombination coefficient for radiative and non-radiative transitions, then the rate equation

$\frac{dn}{dt} = g - \alpha n^2$ (2)

Where $\alpha = (\alpha_1+\alpha_2)$ and n is the number of carriers in the respective band at any time t.

or $\frac{dn}{g-\alpha n^2} = dt$ (3)

$\frac{dn}{g\left[1-\frac{\alpha n}{\sqrt{\alpha g}}\right]^2} = dt$ (4)

Integrating equation (4) and putting $f = \frac{2\alpha n}{\sqrt{4\alpha g}}$, we get (5)

$\int \frac{df}{1-f2} = \sqrt{\alpha g} \int dt$ (6)

Putting $f = tanh\theta$, we obtain, $1 - f^2 = 1 - tanh^2\theta = sech^2\theta$ (7)

Thus, from equation (5), we get

$\int d\theta = \sqrt{\alpha g} \int dt$

or $\theta = \sqrt{\alpha g t} + c$ (8)

where c is an integration constant.

From equations (6) and (7), we get

$tanh^{-1} f = \sqrt{\alpha g t} + c$

or $f = tanh\left(\left(\sqrt{\alpha g}.t\right) + g\right)$ (9)

Where K is another constant.

From equation (5) and (9), we get

$\frac{2\alpha n}{\sqrt{4\alpha g}} = tanh\left(\sqrt{\alpha g}.t\right) + K$ (10)

At $= 0$, $n = 0$, thus from equation (10), we get

$k = 0$

Thus , from equation (10) , we get

$$\frac{2\alpha h}{\sqrt{4\alpha g}} = tanh(\sqrt{\alpha g}.t)$$

or$n = \sqrt{\frac{g}{\alpha}} tanh t \sqrt{\alpha g}$(11)

Case I : Rise of ML Intensity

The rise of intensity of bimolecular ML may be given by

$$I_r = \alpha_1 n^2 = \frac{\alpha_1 g}{\alpha} tanh^2 t\sqrt{g\alpha} \qquad (12)$$

or$I_r = \frac{\alpha_1 g}{\alpha}\left[\frac{2t\sqrt{g\alpha}}{2}\right]^2$

or$I_r = \alpha_1 g^2 t^2$ (13)

Equation (13) indicates that I_r should increase quadratically with t.

Equation (13) shows that when a semiconductor material is cleaved, initially, the ML intensity should increasequadratically with time (t) and finally it should attain a saturation value I_{rs} given by the equation

$$I_{rs} = \frac{\alpha_1 g}{\alpha_1 + \alpha_2}$$

or

$I_{rs} = \frac{2\alpha_1}{\alpha_1+\alpha_2} BWV$ (14)

Case II: Decay of ML Intensity

When the light source will be switched off, the rate of generation, g, of carriers will become zero and equation (2) may be expressed as

$\frac{dn}{dt} = -\alpha n^2$ (15)

If the cleavage is completed at

$t = t_m$, then taking$= \sqrt{\frac{g}{\alpha}}$, at $t = t_m$, we get

$n = \sqrt{\frac{g}{\alpha}} . \frac{1}{(\sqrt{g\alpha})(t-t_m)+1}$(16)

Thus, the decay of ML intensity may be given by

$I_d = \alpha_1 n^2$

$I_d = \frac{\alpha_1 g}{\alpha} . \frac{1}{[(\sqrt{g\alpha})(t-t_m)+1]^2}$ (17)

For $\sqrt{g\alpha}(t - t_m) \gg 1$, we get

$I_d = \frac{\alpha_1}{\alpha^2 (t-t_m)^2}$(18)

The above equation shows that the decay of ML intensity should follow the power law.

For $t = t_m$, using equation (17) the maximum ML intensity may be expressed as

$I_m = \frac{\alpha_1 g}{\alpha} = \frac{2\alpha_1 BWV}{\alpha}$(19)

From equation (17) and (19), we get

$$I_d = \frac{I_m}{[(\sqrt{g\alpha})(t - t_m) + 1]^2}$$

Or$\frac{I_m}{I_d} = [(\sqrt{g\alpha})(t - t_m) + 1]^2$

IV. CONCLUSION

(i) The mechanism related to the formation of crack-induced localized states is responsible for the ML excitation produced during the cleavage of elemental and III-V semiconductors.

(ii) When an elemental or III-V semiconductors is cleaved, initially, the ML intensity increases with time, attains a peak value at the timet_m corresponding to completion of the fracture of the materials, and then it decreases following power law decay.

REFERENCES:

[1]. CHANDRA, B.P. (1985): Nuclear Tracks; 10, 825.

[2].CHANDRA, B.P. and SHRIVASTAVA, K.K.(1978); J. Phy. Chem.Solids; 39, 939.

[3].MEYER, K. OBRIKAT,D. and ROSSBERG, M. (1970): Krist. Tech.; 55,181.

[4]. WALTON, A. J. (1977) : Adv. Phys.: 26, 887.

[5]Dickinson, J. T., and Jensen, L. C. (1986), *J. Amer. Ceramics Soc*. **68**, 235.

[6] Copty-Wergles, K., Nowotny, R., and Hille, P. (1990), *Radiat. Prot. Dosim*. **33**, 339.

[7]Chapman, G. N., and Walton, A. J. (1983a), *J. Phys. C: Sol. St. Phys*. **16**, 5542.

[8] Chandra, B. P. (1996), *Radiat. Effects and Defects Sol*. **138**, 119.

[9] Keszthelyi, C. P., and Bard, A. J. (1973) *J. Electrochem. Soc*.**120**,1726.

[10] Orel, V. E., Opov, Ya. Z., Goraiskii,E.K.,Leshchinskii,I.V.,andKhazanovish, D.M. (1989), *Medits. Tech* **4** 34.