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Effect of energy loss of heavy charged particles on thermoluminescence of aluminum oxide

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Abstract

Heavy charged particles (HCP) deposit their energy on target materials through elastic collision (nuclear energy loss -S_n) and inelastic collision (electronic energy loss- S_e). The nuclear energy loss by ions predominates at low energies (keV/u) whereas electronic energy loss predominates at higher energies (MeV/u). Thermoluminescent (TL) of materials strongly depends on the atomic number and energy of HCP. Pellets of aluminum oxide are irradiated with different HCP having Se in the range 1.3 to 24.83 keV nm^{-1}. Two TL glows with peaks at ~515 K and ~620 K are observed in the samples irradiated with HCP having Se value 24.83, 19.76 and 13.02 keV nm^{-1}. Where as a single and prominent TL glow with peat ~ 530 nm are observed in the samples irradiated with HCP having Se value 4.412 and 1.302 keV nm^{-1}. Further, it is found that TL intensity at ~510 K decreases with decrease in S_e of HCP and is completely absent at lower electronic energy loss.

Keywords: Heavy charged particles; Electronic energy loss; Thermoluminescence, Aluminum oxide,

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1. INTRODUCTION

When an energetic particle such as α-particle, ion or electron hits the atoms of a target different mechanisms of energy or momentum transfer takes place. The most important primary effects are electronic excitation or ionization of individual atoms, collective electronic excitations (e.g. Plasmons), breakage of bonds or cross linking, generation of photons leading to heating of the target, displacement of atoms from the bulk of the target, sputtering of atoms from the surface, generation of ion tracks etc [1]. As energetic ions pass through matter they collide with the atoms and a number of process as can take place. These ions lose their energy in two ways: direct collisions with lattice atoms called elastic scattering corresponds to nuclear energy loss (S_n) and electronic excitations and ionizations called inelastic scattering correspond to electronic energy loss (S_e). The nuclear energy loss by ions predominates at low energies (keV/u) whereas electronic energy loss predominates at higher energies (MeV/u) [2]. Both electronic and nuclear energy losses of an ion depend on the ion species, ion energy and columbic interaction. When an ion moving in a given path Δx it lose an energy ΔE. The mean value of the energy loss ΔE/ Δx (Δx → 0) for a large number of particles is termed as stopping power (S) or range of ion. Range is the sum of the energy losses and is given by

$$S = -\frac{dE}{dx} = S_e + S_n \qquad (1)$$

The energy of the projectile is of particular importance since it leads to creation of various types of defects and ion tracks. The mass of the ion is much higher than the mass of the electron the initial direction of the ion in solid remains almost unchanged. The projected ion range in solid is defined as the mean depth from the target surface at which the ion comes to halt. The range of an ion (R) in solid can be expressed by the rate of energy loss $(dE/dx)_{total}$ along with the trajectory of the ion.

$$R = \int_{E_0}^{o} \frac{1}{\left|\frac{dE}{dx}\right|_{total}} dE \qquad (2)$$

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The main parameters governing the range are the energy and the atomic number of the ion (Z_I) and the atomic number of target (Z_T). Range along the path is the total distance of ion traversed along the trajectory. Since the collisions which leads to deceleration are random process two ions do not have same range. Instead there is a broad distribution in the depths to which individual ions penetrates.

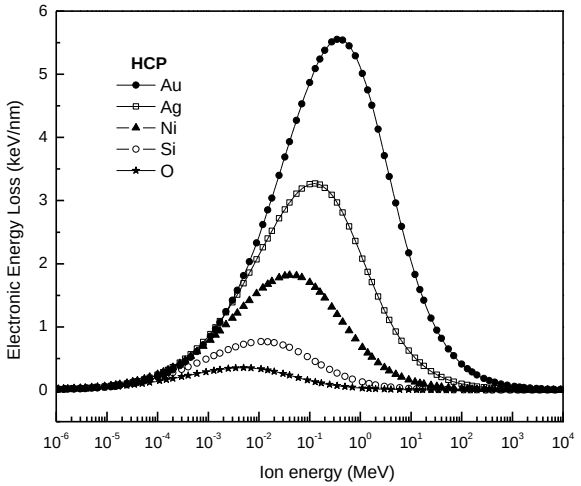

Fig.1: Nuclear energy loss of HCP's as a function their energy.

2. ENERGY LOSS CALCULATIONS

Nuclear energy loss (S_n), electronic energy loss (S_e) and range of different heavy ions are calculated using SRIM – The stopping and range of ions in matter (2010) software [3]. Figure 1 shows the variation nuclear energy loss of different HCP's with their energy. The energy loss dE of an ion by elastic collision in a layer dx is proportional to the atomic density N as well as the total energy transferred in all individual collisions [2]. The interactions between particles with energy (E) and the amount of energy between transferred to a target atom between (T) and T+dT is given by [4]

$$\frac{dP(E)}{dT}dT = Ndx\frac{d\sigma(E)}{dT}dT \qquad (3)$$

where σ (E) is differential scattering cross section. The average energy loss by the moving particle in the distance dx is obtained

$$< dE >= \int T\frac{dp(E)}{dT}dT = N\int T\frac{d\sigma(E)}{dT}\,dTdx \qquad (4)$$

for infinitesimal dx, the nuclear stopping power is given by

$$\left.\frac{dE}{dx}\right|_n = N\int_{T_{\min}}^{T_{\max}} T\frac{d\sigma(E)}{dT}dT \qquad (5)$$

and it is known as nuclear stopping power.

In the present work, I t is found that the maximum energy is deposited on the target nucleus in lower energy region of HCP's. The maximum S_n for gold (Au), silver (Ag), nickel (Ni), silicon (Si) & oxygen (O) is found to be 5.55, 3.27, 1.819, 0.767, and 0.3528 keV nm^{-1} at 0.4, 0.13, 0.04, 0.013 and 0.005 MeV respectively.

Ions lose electrons whose orbital velocities would be less than the ion velocity. This leads to change in ion due to stripping of electron [4]. The effective charge of the ion is given by

$$\frac{Z^*}{Z_r} = \frac{V_I}{(V_0 Z_I^{2/3})} \qquad (6)$$

where Z^* is the charge on the ion, Z_I is the total number of electrons surrounding the ion in ground sate, V_I is the ion velocity and V_o is the Bohr velocity of an electron in the inner most shell of hydrogen atom ($V_o = 2.2\times10^8$ cm s^{-1}). Further, it is experimentally found that the ion charge fraction for a heavy ion is

$$\frac{Z^*}{Z_r} = 1 - \exp\left[\frac{-0.092}{Z^{2/3}}\frac{V_I}{V_0}\right] \qquad (7)$$

From the above equation we have two limit cases.

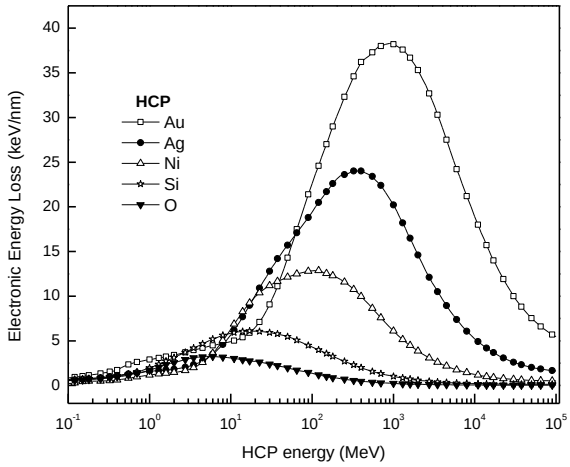

Fig.2: Electronic energy loss of HCP's as a function their energy.

Case 1 : $Z^*/Z_I < 1$, where the ion is not fully striped Fermi and Teller have assumed that the electron gas in a slid behaves like a viscous

medium and that the projectile encounters on its path though electron clouds surrounding each target atom [5]. According to Lindhard Scharff [6] the electronic stopping power is proportional to the velocity of the ions is given in the equation 8. One can understand from the above equation that the S_e is approximately proportional to the velocity or $E^{1/2}$ of the projectile.

$$S_{LS}(E) = \xi_L 8\Pi e^2 a_0 N \frac{Z_I Z_T}{\left(Z_I^{2/3} + Z_T^{2/3}\right)^{3/2}} \left(\frac{V}{V_0}\right) = K_L E^{1/2} \quad (8)$$

Case 2: $Z^*/Z_I > 1$ The ion is fully striped to bare nucleus. At these velocities the charge state of the ion increases and finally becomes fully stripped of all its electrons and moving with a velocity greater than the average velocity of the atomic electrons in the shell of the target atoms. In the fast collision case ($v >> v_o Z_I^{2/3}$) the influence of the incident particle on an atom may be considered as small external perturbation. The stopping cross section decreases with increasing velocity because the particle spends less time in the vicinity of the atom. For non-relativistic ion, the dependence of electronic energy loss may be described by [2,4].

$$S_{BB}(E) = \frac{8\Pi Z_I^2 e^4}{I_o \varepsilon_B} \ln \varepsilon_B \quad where \ \varepsilon_B = \frac{2m_e v^2}{Z_T I_o} \quad (11)$$ where, Io is the excitation energy of the target with Io = $12 + 7Z_T^{-1}$ (eV) for Zr < 1 and Io =9.76+58.5 Zt-1.19 for ZT >/ 12, m_e – mass of the electronic and v_I is ion's velocity.

In the present studies we are used high energy HCP for TL studies. Figure 2 shows the variation nuclear energy loss of different HCP's with their energy. The maximum energy is deposited on target electrons in higher energy region. The maximum S_n for gold (Au), silver (Ag), nickel (Ni), silicon (Si) & oxygen (O) is found to be 38.3, 24, 12.87, 6.09 and 3.253 keV nm^{-1} at 900, 350, 110, 18 and 5.5 MeV respectively.

Range of ions: The projected ion range in solid is defined as the mean depth from the target surface at which the ion comes to halt. The range of an ion (R) in solid can be expressed by the rate of energy loss $(dE/dx)_{total}$ along with the trajectory of the ion [7, 8]

$$R = \int_{E_0}^{o} \frac{1}{\left|\frac{dE}{dx}\right|_{total}} dE \quad (13)$$

The main parameters governing the range are the energy and the atomic number of the ion (Z_I) and the atomic number of target (Z_T). Range along the path is the total distance of ion traversed along the trajectory. Since the collisions which leads to deceleration are random process two ions do not have same range. Instead there is a broad distribution in the depths to which individual ions penetrates. Figure 3 shows variation of range of different HCP with their energies. And in the inset of figure 3 Range of 100 MeV ions as a function of their atomic weight is given. It is found that the range of ions for Au, Ag, Ni, Si and O ions is 8.03, 8.55, 11.05, 19.82 and 53.79 respectively.

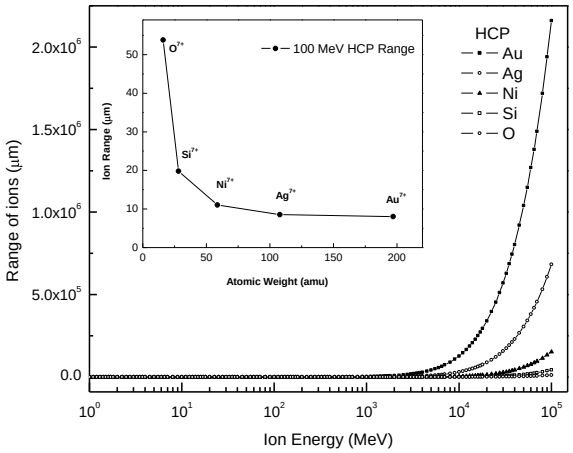

Fig.3: Variation of range of different HCP with their energy. Inset: Range of 100 MeV ions as a function of their atomic weight.

3. EXPERIMENTAL

In the present work, pellets of aluminum oxide are irradiated with different HCP's at Inter University Accelerator Centre (IUAC) (Formerly known as Nuclear Science Centre), New Delhi. The accelerator at IUAC is a 15 UD tandem electrostatic accelerator [9] capable of accelerating any ion from proton to uranium (except inert gases) to the energies from 50 MeV to 200 MeV. Thermoluminescence spectra are recorded using Harshaw TL Reader. The variation if energy loss of different 100 MeV HCP's as function of their atomic weight is shown in figure 4. Sn is negligible when compared to Sn.

4. RESULTS AND DISCUSSIONS

120 MeV swift Au^{9+} ions deposit an Se of 24.83 keV nm^{-1} on microcrystalline aluminum

oxide. The sample exhibits a strong TL glow peak at ~620 K with shoulder at ~515 K when irradiated with Au^{9+} ions [10]. TL glow curves of 100 MeV (Se = 19.76 keV nm^{-1}) swift Ag^{7+} ion irradiated aluminum oxide shows prominent TL glow with peak at ~ 620 K with a shoulder at ~ 510 K on lower temperature side. Two TL glows - a well resolved one with peak at ~615 K (T_{m2}) and an unresolved one at ~510 K (T_{m1}) are

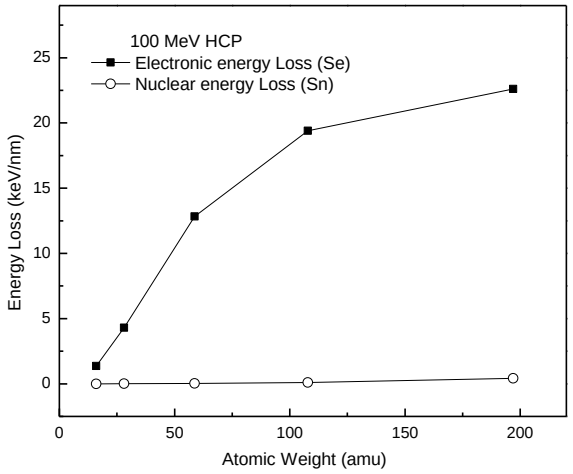

Fig.4: Energy of 100 MeV HCP's as function their atomic weight.

recorded in 100 MeV swift Ni^{7+} ion (Se = 13.02 keV nm^{-1}) irradiated microcrystalline Al_2O_3. It is observed that the unresolved TL glow is observed only in lower fluence but at higher fluence it is completely absent. TL glow curves of samples irradiated with 100 MeV swift Si^{7+} ions (Se = 4.412 keV nm^{-1}) shows single prominent glow with peak at 546 K [11]. A single and prominent well resolved TL glow with peak at 520 K is observed 100 MeV O^{7+} ion (Se = 1.302 keV nm^{-1}) irradiated samples. Microcrystalline Al_2O_3 irradiated with Au^{9+}, Ag^{7+} and Ni^{7+} ions shows second order characteristics and a prominent TL glow along with shoulder on lower temperature side [12]. However, the samples irradiated with Si^{7+} and O^{7+} shows first order kinetics and a single and prominent TL glow without any shoulder.

5. CONCLUSIONS

Al_2O_3 samples exhibits two TL glows when irradiated with higher atomic weight ions such as Au, Ag & Ni. These ions deposit high energy on the target material leads to two different types of electron trap centers responsible for TL emission. Whereas Al_2O_3 exhibits a single TL glow peak when irradiated with lower atomic weight ions such as Si and O.

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References:

1. K. Schwartz, C. Trautmann, T. Steckenreiter, et.al. Phy. Rev. **B 58** (1998) 11232
2. J.F. Ziegler, J.P. Biersack and U. Littmark, The Stopping and Range of Ions in Solids, Pergamon Press, New York, 1985.
3. www.srim.org
4. K. Bethe, Ion tracks and Microtechnology, Federal Republic of Germany 1990.
5. S.P. Ahlen, Rev. Mod. Phys. **52** (1980) 121.
6. J. Lindhard, M. Scharff and H.E. Schiott, Mat. Pys. Medd. Dan. **33** (1963) 14.
7. J.W. Mayer and E. Rimini, Ion Beam Band Book for Material Analysis, Academic Press, New York, 1977.
8. W.K. Chu, in: J.P. Thomas and A. Cachard (Ed), Material Characterization Using Ion Beams, 1977, p 3
9. D. Kanjilal, S. Chopra, M. Narayanan, et. al., Nucl. Instr. and Meth. **A 238** (1993) p 97.
10. K.R. Nagabhushana, B.N. Lakshmi Narasappa and Fouran Singh, *Radiat. Meas.* 43S1 (2008) S561-S565
11. K.R. Nagabhushana, B.N. Lakshmin Nrasappa, D. Revannasiddaiah, D. Haranath and Fouran Singh, *Proc Iint. Conf. Lum. and its Appln,* (2008) p157
12. A.J.J. Bos, Nucl. Instr. and Meth. Phys. Res. **B 184** (2001) 3.