Modeling influence factors of Al_2O_3:C optically stimulated luminescence detectors (OSLDs) exposed to radiotherapy beams

To describe the charge transportation processes that lead to the OSL response of Al_2O_3:C OSLDs we used a band diagram model consisting of three electron traps (shallow, ST; main, MDT; and deep, DT) and two luminescence recombination centers (RC1 and RC2) (Fig 1) (Denis et al 2011, J. Appl. Phys. 109:104906; Chen et al 2006, J. Appl. Phys. 99:033511). The system of differential equations that represents the transport of charge carriers (electrons and holes) during irradiation, relaxation, stimulation and bleaching of the OSLD is presented in the right. The meaning of each variable and parameter can be inferred from Fig 1.

Irradiation

$$\frac{dm_1}{dt} = -A_{m_1} m_1 n_c + B_1(M_1 - m_1)n_v \quad (1)$$

$$\frac{dm_2}{dt} = -A_{m_2} m_2 n_c + B_2(M_2 - m_2)n_v \quad (2)$$

$$\frac{dn_1}{dt} = -s n_1 e^{-E/(k_B T)} + A_{n_1}(N_1 - n_1)n_c \quad (3)$$

$$\frac{dn_2}{dt} = A_{n_2}(N_2 - n_2)n_c \quad (4)$$

$$\frac{dn_3}{dt} = A_{n_3}(N_3 - n_3)n_c \quad (5)$$

$$\frac{dn_v}{dt} = X - B_1(M_1 - m_1)n_v - B_2(M_2 - m_2)n_v \quad (6)$$

$$\frac{dn_c}{dt} = \frac{dm_1}{dt} + \frac{dm_2}{dt} + \frac{dn_v}{dt} - \frac{dn_1}{dt} - \frac{dn_2}{dt} - \frac{dn_3}{dt} \quad (7)$$

Relaxation, stimulation and bleaching

$$\frac{dm_1^*}{dt} = A_{m_1} m_1 n_c - \frac{m_1^*}{\tau_1} \quad (8)$$

$$\frac{dm_1}{dt} = -\frac{m_1^*}{\tau_1} \quad (9)$$

$$\frac{dm_2^*}{dt} = A_{m_2} m_2 n_c - \frac{m_2^*}{\tau_2} \quad (10)$$

$$\frac{dm_2}{dt} = -\frac{m_2^*}{\tau_2} \quad (11)$$

$$\frac{dn_1}{dt} = -s n_1 e^{-E/(k_B T)} + A_{n_1}(N_1 - n_1)n_c \quad (12)$$

$$\frac{dn_2}{dt} = -f_{\lambda_2} n_2 + A_{n_2}(N_2 - n_2)n_c \quad (13)$$

$$\frac{dn_3}{dt} = -f_{\lambda_3} n_3 + A_{n_3}(N_3 - n_3)n_c \quad (14)$$

$$\frac{dn_c}{dt} = \frac{dm_1}{dt} + \frac{dm_2}{dt} - \frac{dn_1}{dt} - \frac{dn_2}{dt} - \frac{dn_3}{dt} \quad (15)$$

OSL signal

$$I(t) = -\frac{dm_1}{dt} - \frac{dm_2}{dt} \quad (16)$$

Fig 2 represents simulated OSL curves for the two different OSL emissions of Al_2O_3:C. Our simulation results showed that the OSL signal: 1) depends on irradiation temperature in the temperature range relevant to medical dosimetry (15 to 40°C); 2) fades as a function of time elapsed since irradiation. The fading is dose dependent; 3) has a non-linear dose-response, which depends on the detected OSL emission (Fig 3); and 4) changes as a function of accumulated dose and resetting method. Our results suggest that it is important to thoroughly characterize the Al_2O_3:C OSLD response for accurate dose measurements. The magnitude of each influence factor investigated in this work may be determined experimentally.

Impact: The proposed model may be used to understand the role of important influence factors on Al_2O_3:C OSLDs, which will help on the development of reference dosimetry protocols based on measurements using Al_2O_3:C OSLDs.

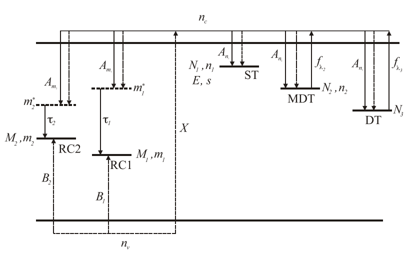

Fig 1: Dashed and solid lines represent the processes during irradiation and stimulation phases, respectively.

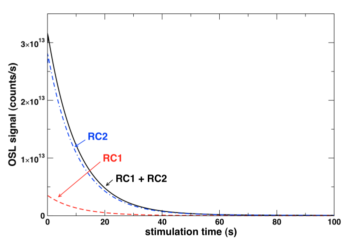

Fig 2: Simulated CW-OSL curves. RC1 and RC2 are emissions from two luminescence centers.

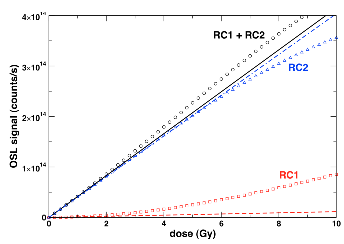

Fig 3: Simulated CW-OSL dose response curve showing the non-linear behavior.