Supporting Information

X-Ray Induced Photodynamic Therapy: A Combination of Radiotherapy and Photodynamic Therapy

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Singlet oxygen generation efficiency

The $^1O_2$ production efficiency was calculated based on a published method [1]. Briefly, the X-PDT process can be broken into three steps. Firstly, SAO:Eu nanoparticles were irradiated by X-ray to emit luminescence. Second, the XEOL activates near-by photosensitizers (MC540). Lastly, $^1O_2$ is produced. From energy transformation perspective, the whole process can be regarded as a conversion from the electromagnetic energy (the ionizing radiation) to chemical energy (the $^1O_2$). The conversion efficiency (η) can be calculated from the following equation:

$$\eta = \frac{E_c}{E_{em}}$$

where E_c is the chemical energy, i.e. the energy increase when oxygen molecules are converted to singlet oxygen molecules.

The energy difference between the lowest energy of O_2 in the singlet state and the lowest energy in the triplet state is about 94.3 kJ/mol (i.e. 0.98 eV) [2, 3]. Therefore, E_c can be calculated from:

$$E_c = 0.98 \times N_A \times Y(\text{J}) = 0.94 \times 10^5 \times Y(\text{J})$$

where N_A is the Avogadro's constant (6.02×10^{23}), 1 eV=1.6×10^{-19} J, and Y (mol) is the amount of singlet oxygen generated from the X-PDT process.

Y can be estimated from our singlet oxygen generation data (Figure 2b) using a published method [1]. When there is excess MC540, the ratio between the reactants is 1:1 in the O_2-$^1O_2$-

MC540 reaction [1, 3-6]. Hence, Y is equal to the amount of the activated MC540 resulting from the photodynamic effect:

$$Y = n_0 \times (b_m - b_c) = W_{MC540} / M_{MC540} \times (b_m - b_c) = 4.5 \times 10^{-9} \times (b_m - b_c)(\text{mol})$$

where n_0 is the initial content of MC540 (5 wt% of 1 mL solution of 50 mg/L, M_{MC540} = 553.6 g/mol), and (b_m-b_c) is the relative percentage change of SOSG fluorescence signals [1]. As shown in Figure 3b, the value of (b_m-b_c) is approximately equal to the difference between the control group and the MC540-SAO:Eu@mSiO_2 group in the ordinate value at a given radiation dose. From the above two equations, E_c can be rewritten as:

$$E_c = 0.94 \times 10^5 \times Y = 4.2 \times 10^{-4} \times (b_m - b_c)(\text{mol})$$

Meanwhile, E_{em} is the electromagnetic energy in the form of X-ray, which is dependent on the radiation dose (D, Gy). By definition, 1 Gy is equal to an absorbed dose of 1 J/kg. Considering that 1 mL (1 g) aqueous solution was used in the experiment, E_{em} can thus be calculated as:

$$E_{em} = 1 \times 10^{-3} \times D(\text{J})$$

Hence,

$$\eta = \frac{E_c}{E_{em}} = \frac{4.2 \times 10^{-4} \times (b_m - b_c)}{1 \times 10^{-3} \times D} = 0.42 \times \frac{(b_m - b_c)}{D}$$

Using the above equation we computed $^1O_2$ production efficiency at different irradiation doses and the results were listed in Table S1.

Table S1. $^1O_2$ production efficiency (η) of X-PDT at different X-ray radiation doses (D) (X-ray dose rate is 0.2 Gy/min).

D/Gy	**b_m-b_c**	**η**
1	7%	2.9%
2	20%	4.2%
3	32%	4.5%
4	41%	4.3%

It can be seen that η values at different D are comparable. An average of the η values in Table 1, 3.9%, was reported in the main text.

Supporting Figures

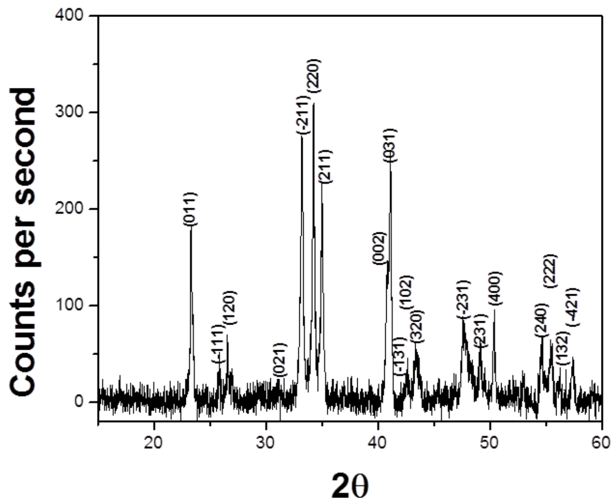

Figure S1. X-ray diffraction (XRD) analysis result. The main product is monoclinic $SrAl_2O_4$ (JCPDS #74-0794).

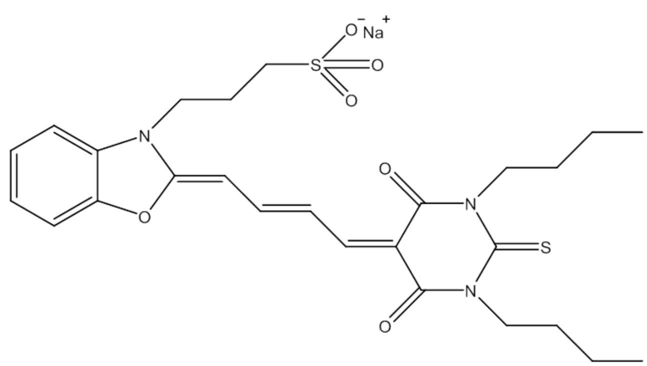

Figure S2. Chemical structure of merocyanine 540 (MC 540).

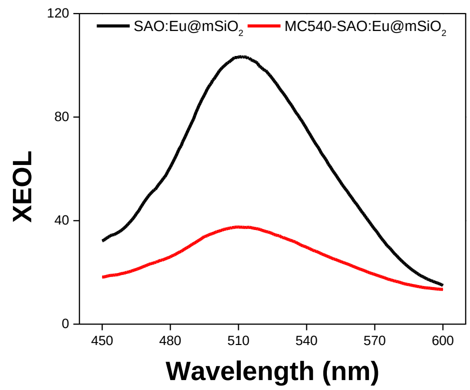

Figure S3. X-ray excited optical luminescence (XEOL) of SAO:Eu@mSiO$_2$ before and after loaded with MC540 photosenstizers.

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