Singlet oxygen luminescence detection with a fibre-coupled superconducting nanowire single-photon detector

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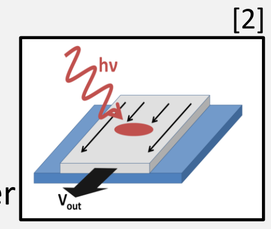
Abstract

Direct monitoring of singlet oxygen ($^1O_2$) luminescence provides a direct dosimetry technique for photodynamic therapy in the treatment of cancer. $^1O_2$, an excited state of the oxygen molecule, is an intermediate in many biological processes. We employ a superconducting nanowire single-photon detector (SNSPD) to record $^1O_2$ luminescence at 1270 nm wavelength from a model photosensitizer (Rose Bengal) in solution, crucially this was also performed using a fibre based illumination and collection scheme [1].

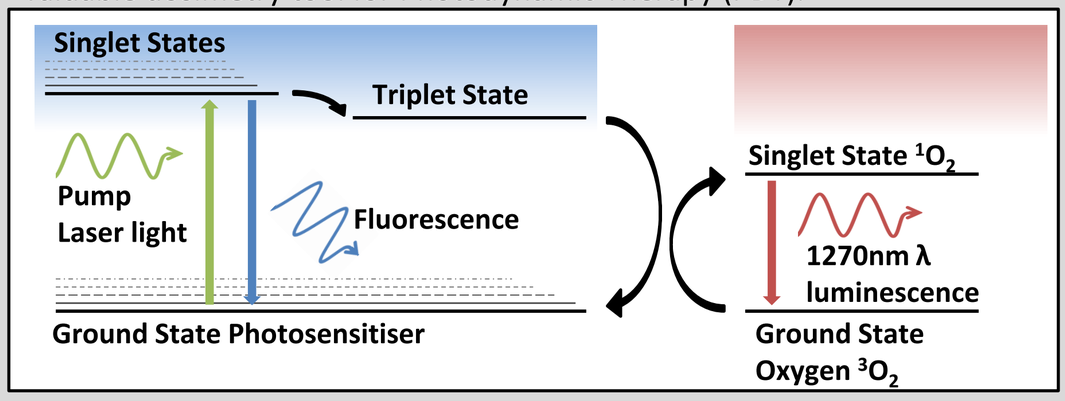
Superconducting Detector

- A closed-cycle refrigeration system eliminates the need for cryogens.
- Improved performance over PMTs for infrared single photon detection: [2]
  - High detection efficiency
  - Low noise
  - Low timing jitter



Singlet oxygen

- Singlet Oxygen Luminescence Dosimetry (SOLD) has been shown to be a valuable dosimetry tool for Photodynamic Therapy (PDT).



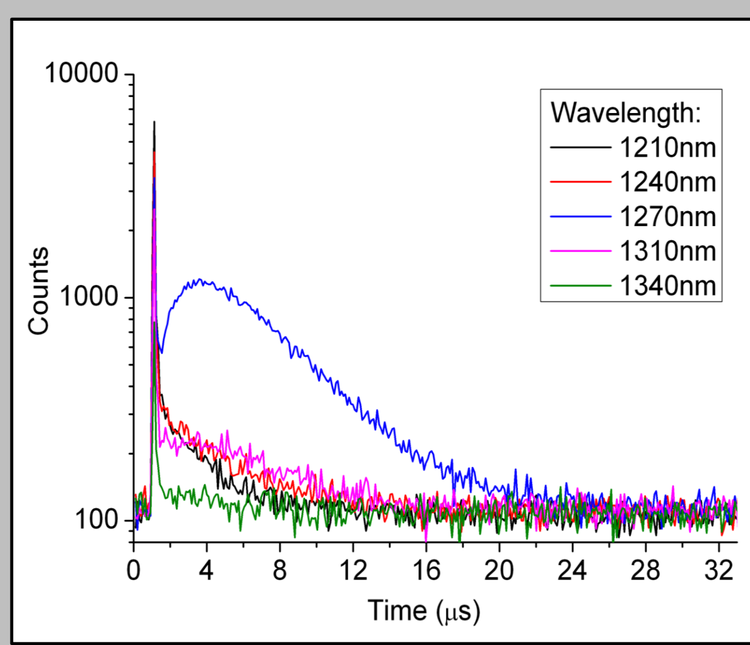
Free space singlet oxygen luminescence detection

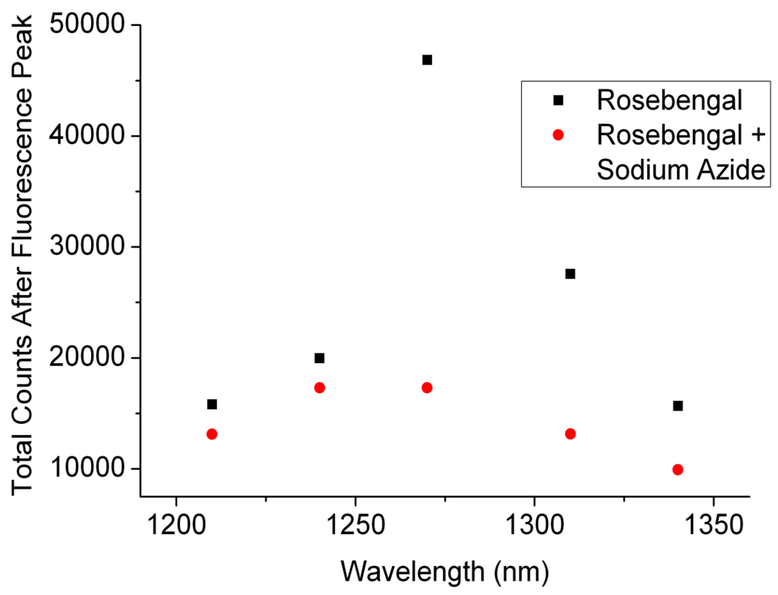
- A 523 nm wavelength laser source was directed into a cuvette filled with photosensitiser (Rose Bengal).
- Collected light emission was sent through a series of filters, before being coupled into telecoms fibre and directed onto the superconducting detector.

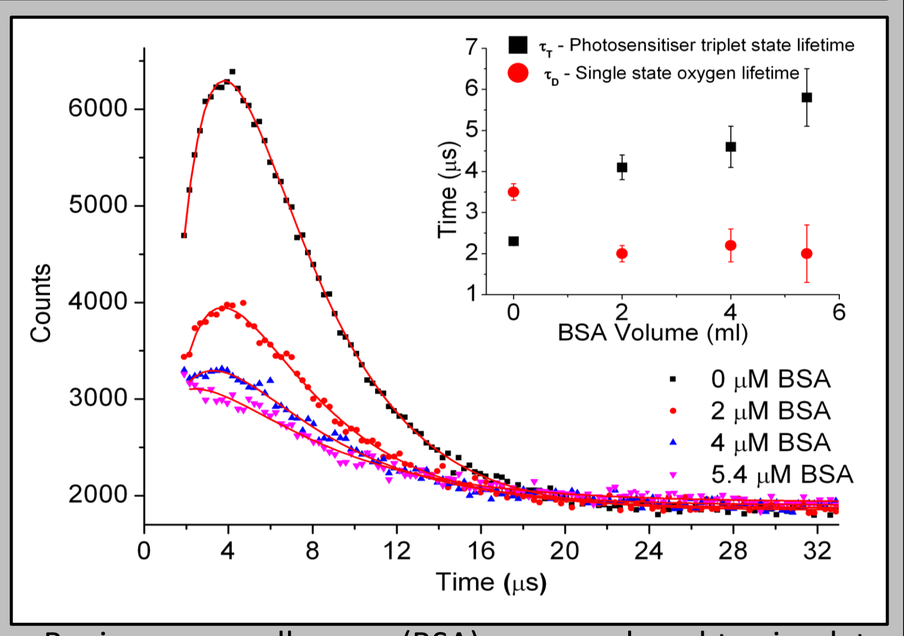
- It has been demonstrated [3] that the concentration of $^1O_2$ at a time, *t*, is given by:

$$\left[{}^1O_2\right](t) = N\sigma\left[S_0\right]\Phi_D\frac{\tau_D}{\tau_T-\tau_D}\left[exp\left(\frac{-t}{\tau_T}\right)-exp\left(\frac{-t}{\tau_D}\right)\right] \quad \text{Eq. 1}$$

- This equation was least squares fitted to the data taken to confirm the presence of $^1O_2$.
- Further confirmation was made by the introduction of Sodium azide: a known quencher.

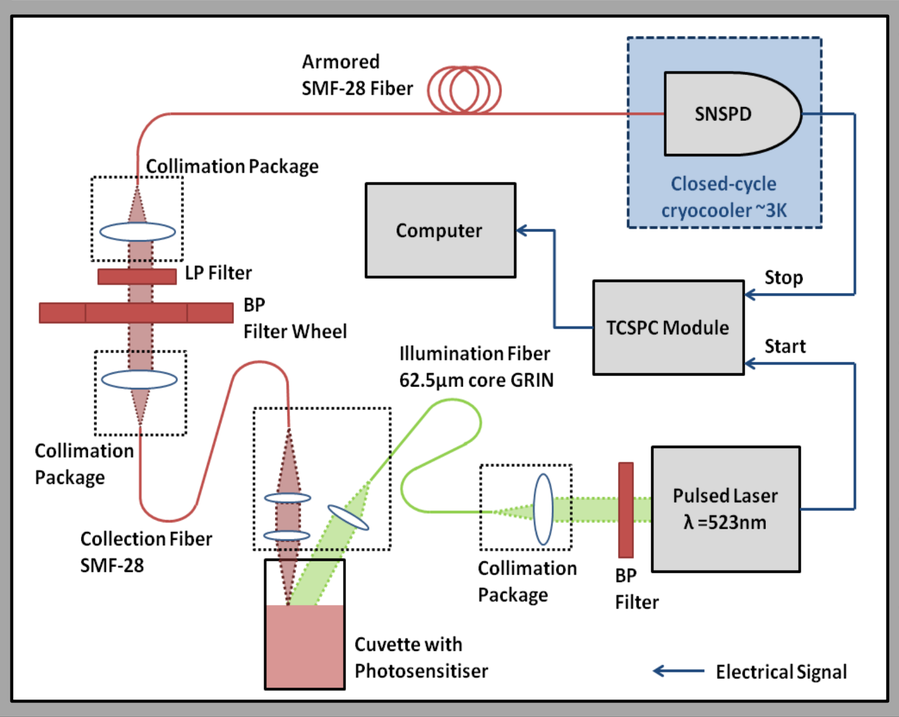






- Bovine serum albumen (BSA) was employed to simulate a proteinaceous biological environment
- The evolution of the photosensitiser triplet and $^1O_2$ singlet-state lifetimes was successfully observed as the BSA concentration was increased.
- The photosensitiser triplet state lifetime increases, likely due to shielding of the photosensitiser from the diffusion of oxygen molecules.
- The decrease in $^1O_2$ lifetime has also been seen in previous studies and was attributed to quenching by the protein [3].

Fibre-based singlet oxygen luminescence detection



- An optical fibre delivery and collection scheme, as shown to the left, demonstrates a marked advance in SOLD for clinical applications.
- The collected signal was approximately 2 orders of magnitude lower than with free-space collection.
- Longer acquisition times required to obtain a reliable measurement.
- Numerous technical improvements could substantially address the loss
- Luminescence light collection could be increased using a larger-diameter fibre
- Next-generation detectors with near 100% efficiency are under development [4].

References

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