Fluorescence blinking is a universal phenomenon in single molecule/particle detection of fluorophores. Much attention has been directed toward unraveling the cause of blinking, the underlying mechanism for the inverse power-law blinking statistics, and the environmental effects on blinking. More recent developments in fluorescence blinking include less toxic fluorescence markers, blinking suppression, single-photon sources, and solar energy conversion.

Intermittency (or blinking) is a very interesting and intriguing phenomenon commonly observed in single molecule/particle spectroscopy. Such behavior is not exclusive to nanosciences, it has been observed in the macroscopic world involving non-linear dynamic systems, including geomagnetic field reversal, sun spot activity, and non-linear electronic circuits near the Hopf bifurcation point (1). Fluorescence blinking has drawn much attention in the last decade due to the advance in confocal microscopic techniques. With these techniques, researchers can zoom into a micron-size area of a highly dispersed sample to investigate a single molecule or nanoparticle. Such an approach avoids the complication due to sample heterogeneity and conformation variations among an ensemble system; therefore, it offers useful information that is not readily available by ensemble measurements.

Under continuous light illumination, each individual fluorophore exhibits random bursts of photons like telegraphic signaling. Such stochastic on-off behavior appears to be quite universal, and it has been observed in single fluorescent proteins (2), semiconductor nanoparticles (3) (quantum dots (QDs), nanorods, and nanowires), polymer segments (4), and even noble metal nanoclusters. The fluorescence intensity histogram from a single fluorophore often consists of time intervals with quasi-binary or more complicated on and off intensity levels. More intriguingly, the waiting time distribution of these on- and off-events does not usually follow a more well-known exponential decay, but rather exhibits an inverse power law with an exponent close to 1.5 (5). At a longer time scale, breakdown of this power-law behavior is often seen for the on-events, especially if the excitation intensity or the nanoparticle size is increased (6).

Although some details of the blinking mechanism still need to be resolved, it is widely believed that blinking occurs due to the charge transfer between a photo-excited excitonic state, which is neutral in charge, and a dark state with a hole residing inside the core and an electron in surface trap states. The positively charged QD appears dark due to fast Auger relaxation assisted by the hole in the core. Several theoretical models have been proposed to explain blinking (7); the first-passage model with a fluctuating barrier, also known as the diffusion-control reaction model (8), appears to be able to explain many experimental findings, including spectral diffusion, the observed exponent around 1.5, the presence of a long-time exponential or stretched exponential bending tail, the dependence of this bending rate on excitation intensity, particle size, and temperature, etc.

Although blinking has been an interesting subject for researchers, it is a nuisance for the biomedical applications of nanoparticles as fluorescence markers in fluorescence imaging. The annoyance caused by blinking is fully understandable for anyone who is driving a car on a pitch-dark night with the headlights blinking randomly. More recently, several schemes to suppress blinking have been proposed. For example, one could cap CdSe QDs with a thick inorganic CdS layer or organic ligands to block the electron transfer from the core to the surface trap states (9). This approach of making a giant multishell QD, however, leads to degraded fluorescence yield. Another alternative to achieve blinking suppression was demonstrated by coupling the QDs to silver nanoprisms (10) (see Fig. 1). Via plasmonic effects, one could enhance

![Fig. 1. Fluorescence intensity histogram for single CdSe/ZnS QDs on glass showing a typical blinking trace with on-off events (red) and for QDs coupled to silver nanoprisms showing no off-events, but with an enhanced intensity level (blue).](image-url)
fluorescence yields, radiative recombination rate and yet retard the Auger relaxation. Moreover, anti-bunching was demonstrated, leading to potential applications in quantum information technology as single-photon sources on demand.

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