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Glowing microfluidics without external light source

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ABSTRACT

We observed that pumping gold and silver nanoparticles into a microfluidic device fabricated in polydimethylsiloxane prolongs the glow time of luminol. We have demonstrated that the intensity of chemiluminescence in the presence of nanospheres depends on the position along the microfluidic serpentine channel. We show that the enhancement factor can be controlled by the nanoparticle size and material. Spectrally, the emission peak of luminol overlaps with the absorption band of the nanospheres, which maximizes the effect of confined plasmons on the optical density of states in the vicinity of the luminol emission peak. These observations, interpreted in terms of the Purcell effect mediated by nano-plasmons, form an essential step toward the development of microfluidic chips with gain media. Practical implementation of the discovered effect will include improving the detection limits of chemiluminescence for forensic science, research in biology and chemistry, and a number of commercial applications.

INTRODUCTION

Chemiluminescence is a fascinating optical effect that is used in various applications, from forensic science to industrial biochemistry. Luminol is a chemical that exhibits chemiluminescence (Figure 1), emitting a blue glow. Approximately five decades ago, luminol was used for the first time to analyze a crime scene in Germany. Since then, it has become a very popular criminology tool, as it can reveal blood stains. A mixture of luminol, hydrogen peroxide, and a thickening agent can be sprayed on surfaces contaminated with blood traces. If catalyzed by metal ions, such as the iron contained in blood hemoglobin, the mixture will glow.

MATERIALS AND METHODS

Using fabricated reusable microflow device with a serpentine channel 600 μm in width, 200 μm in depth we record the intensity of emitted light with charge-coupled-device (CCD). We study the effect of gold and silver nanoantennas on the efficiency of chemiluminescence emission by luminol, by performing the spectrally resolved transmission measurements in the frequency range from 405 to 645 nm. In addition, we measure the chemiluminescence of luminol triggered by metallic nanoparticles and 600 μm in length, formed in polydimethylsiloxane (PDMS). We calculate the flow rate of the luminol in the channel as:

1) $$Flow\ rate = \frac{dVolume}{dt} = 0.35\ \mu l/sec$$

The cross section of the channel is S=$\pi R^2 = 3.14(100\mu m)^2 = 3.14 \cdot 10^{-4} cm^2$.

The linear propagation velocity of luminol is:

2) $$Velocity_x = \frac{Flow\ rate}{S} = \frac{0.35\times10^{-6}10^3 cm^3}{3.14\times10^{-4} cm^2 sec} \approx 1 \frac{cm}{sec}.$$

We repeat the experiment with gold and silver nanoantennas having diameters of 20, 40 and 60 nm.

RESULTS AND DISCUSSION

Experimental apparatus:

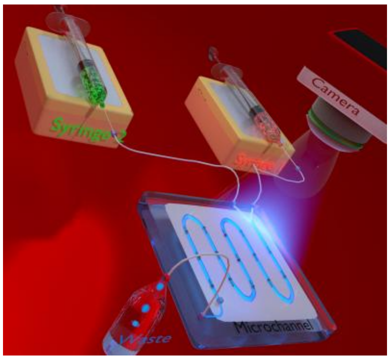

Figure 1: Schematic of the system: microfluidic device with syringes that pump fluids through the serpentine on a Polydimethylsiloxane(PDMS) microchannel on a chip. Organic waste is discarded through the outlet liquid reservoir. The emitted chemiluminescence signal isdetected by the CCD.

A source of light (a luminol molecule in our case) emits photons to a medium characterized by some given density of photonic states. If at the emission frequency at this density is lower than in vacuum, the radiative efficiency is increased. In the presence of metallic nanoparticles, the density of photon states increases resonantly at certain characteristic frequencies associated with the plasmon modes of metallic objects. If the emission band of luminol overlaps with the spectral region of the plasmon-induced increase in the photonic density of states in the medium, the radiative efficiency of luminol is enhanced

CONCLUSIONS

In conclusion, we have demonstrated multi-fold enhancement of the chemiluminescence intensity during flow injection in a microfluidic chip. We have observed that pumping nanoparticles into a microfluidic device fabricated in polydimethylsiloxane (PDMS) prolongs the glow time of luminol. The enhancement of chemiluminescence by metallic nanoparticles may be due to the following factors: 1) the uniform intensity of chemiluminescence emission due to thorough mixing of the reagents and maximized intensity due to the location of emitters at distances that are favorable for interaction with the metal nanoparticles (antennas) and 2) the collective response of conduction electrons in the metal. The optical field of plasmon modes is localized in the vicinity of the surfaces of metallic nanoparticles. As a result, the lightning antenna effect exhibits resonant amplification if the excitation frequency coincides with a localized surface plasmon resonance (LSPR) of the particle.

REFRENCES

Karabchevsky, A. et al (2016), "Tuning the chemiluminescence of a luminol flow using plasmonic nanoparticles", Light Science and Applications *In Press*