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Spatial Sensing of Bacteria by Photoluminescence of Single-Layer MoS_2

Label-free cell observation is important to understand cell innate activity. Two-dimensional (2D) materials represented by graphene have gained a wide attention also in the field of bio-sensing application. For example, it has been reported that graphene modified by self-assembled peptide was utilized for a bioselective detection at single cell level [1], and graphene Raman mapping enabled to visualize cellular metabolic activity with subcellular resolution [2]. Due to its direct bandgap, single-layer Molybdenum disulfide (MoS_2) shows strong photoluminescence under photo-excitation. The intensity decreases when the internal electron density increases, which can be modified by molecules adhere on the surface [3][4]. It has been also reported that the photoluminescence (PL) intensity greatly changes when pH changes under water [5]. In this work, we utilized this characteristic to visualize living cells or bacteria activity.

In more details, we aimed to visualize the activity of lactobacillus which consumes sugar and produces lactic acid, resulting in the change of pH around them. This activity is used for fermentation of yogurt and some other food production. Lactobacillus rhamnosus GG (LGG) was utilized in this research, since it has been paid attention in the field of probiotics that bacterium help our health improvement [6]. We believe that visualizing lactobacillus activity will help to select the better cells that could be more powerful for the probiotics. It would give us better understanding of the mechanism on probiotic activity of LGG.

In the experiment, MoS_2 was first synthesized by Chemical vapor deposition (CVD) from MoO_2 and Sulfur powder, and then it was transferred onto a glass substrate with gold electrodes. The PL image was observed by an inverse microscope with an EM-CCD (Figure 1). MoS_2 PL intensity was modulated through applied voltage on a gold electrode and showed threshold voltage. PL intensity of MoS_2 was measured under different concentration of lactic acid and applied voltage. Under a constant voltage, MoS_2 PL intensity increased and then decreased as the concentration of LA was increased (Figure 2). Adhesion of LGG on MoS_2 was evaluated. We found that LGG adhered more onto MoS_2 than glass substrate. MoS_2 with LGG showed a PL pattern that correlates with LGG adhesion (Figure 3). The contrast was tuned *via* the applied voltage. Time dependence of PL image was also observed. This spatial modulation of MoS_2 PL could be driven by the adhered LGG which is probably related to the shift of threshold voltage arise from the electron density in MoS_2.

Through these results, we demonstrated that MoS_2 has the potential to visualize cell activity label-freely thorough its photoluminescence.

References

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[4] Mouri, S., Miyauchi, Y., & Matsuda, K. (2013). Nano Letters, 13(12), 5944–5948.
[5] Zhang, W., Matsuda, K., & Miyauchi, Y. (2018). Journal of Physical Chemistry C, 122(24), 13175–13181.
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Figures

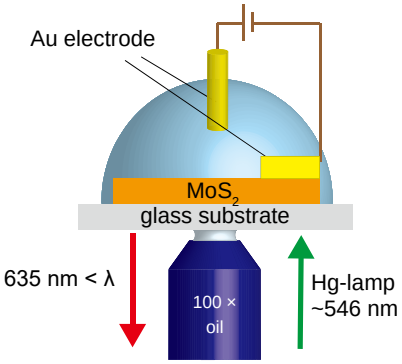

Figure 1: Schematic of measurement setup for fluorescent imaging of MoS_2 under solution.

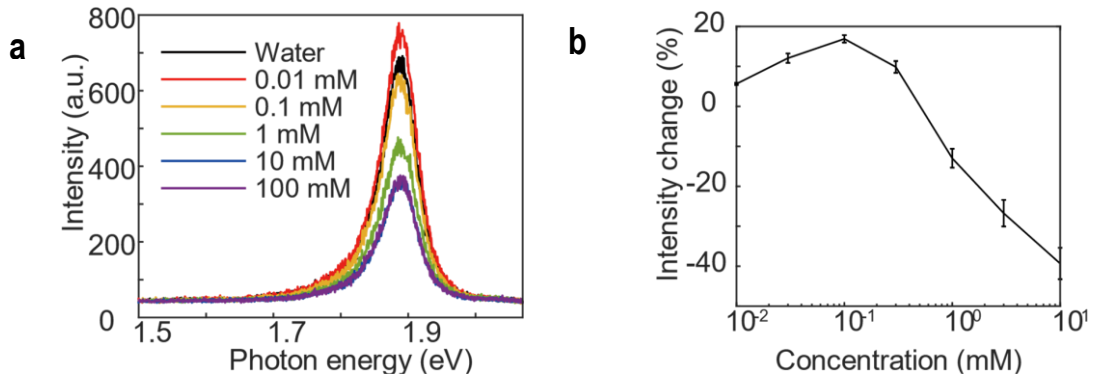

Figure 2: Response of MoS_2 PL intensity to concentration of lactic acid under constant voltage. **a**. MoS_2 spectra under different concentrations of lactic acid. **b**. Average intensity of MoS_2 PL *vs* concentration of lactic acid.

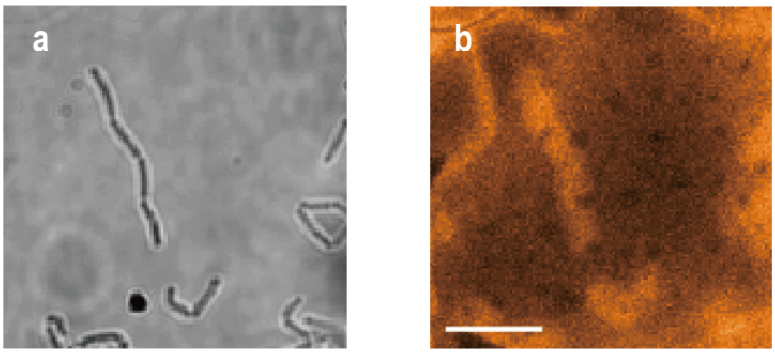

Figure 3: **a**. Optical transmission image of LGG on MoS_2. **b**. PL image of MoS_2 at the same location. Intensity of MoS_2 PL increased under the LGG. The inset shows 10 μm.