VISUALIZATION OF ION LIGHTNING THROUGH NANOFLUIDIC MEMBRANE

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In this work, for the first time, we visibly generated a lightning through nanoporous membrane in micro/nanofluidic platform. Firstly, a micro bubble was formed by Joule heating inside a microchannel with an application of electric field (**E**) of 100 V/cm. Secondly, vapor phase was changed into plasma phase and bright light was emitted at |**E**| = 500 V/cm. Finally, it was observed that emitted light propagated through the perm-selective nanoporous membrane along with strong cation flux. These findings would have a scientific significance for the visualization of cation trajectories inside the nanoporous membrane.

With the development of micro fabrication technology, it has been possible to experimentally demonstrate the hydrodynamic theory, which has been known only as a formula, and new physical phenomena have also been found. Particularly when a voltage is applied to both ends of the nanoporous membrane, the electrical double layer is overlapped and perm-selectivity is initiated. This is a key mechanism in the field of nano-electrokinetics and is the starting point of various studies. [1] Since it is difficult to directly observe the ion transportation phenomenon inside the nanoporous membrane, limited studies using indirect experimental evidences have been carried out. As a result, the debate is still ongoing. On the other hand, studies related to the plasma generation at the atmospheric pressure and the low temperature condition in the microfluidic device have already been reported, but due to the obvious disadvantages such as high voltage operation and the instability [2-3], there have been few studies on the application of inherent luminescence characteristics. Here, we firstly tried to observe the flow of ions through the nanoprous membrane by using a plasma discharged visible light as shown in *Fig. 1*.

For a demonstration, micro-nanofluidic hybrid device was fabricated using PDMS molded microchannel and Nafion nanoporous membrane as shown in *Fig. 2*. Firstly, micro-sized bubble was formed at the center of a microchannel filled with KCl 2 M when a voltage (V=100 V, |**E**|=100 V/m) was applied as shown in *Fig. 3(a)*. It was remarkable that delay (3 sec) of bubble formation was due to Joule heating. Current was linearly increased from 0 to 52 V, but sharply dropped at 53 V as shown in *Fig. 3(b)*. It meant that fluidic channel was shorted because of bubble formation inside the channel. Secondly, we changed voltage configuration and clearly observed that vapor phase was changed into plasma phase with an applied voltage of 500 V (|**E**|=500 V/m) as shown in *Fig. 4(a)*. Discharged bright light was continuously emitted along with the movement of bubbles inside the microchannel. *Fig. 4(b)* showed that the luminous point was moved into the nanoporous membrane at t>0.42 sec and emitted like a lightning. This phenomenon demonstrates the great significance of visualizing the real-time migration path of the ions in nanoporous membrane.

It is expected that various products such as active nano light emitting, nano imaging, and ion analyzing devices can be obtained by widening the limited research range in the field of micro-plasma.

Word Count: <= 497

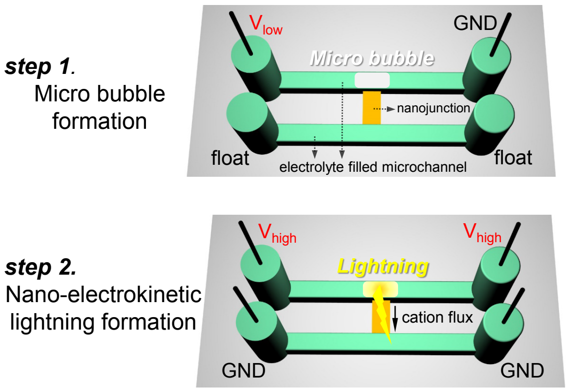

Fig.1 Schematic diagram of the micro bubble formation in a microfluidic channel (step 1) and the electrokinetic lightning formation through the nanojunction (step 2).

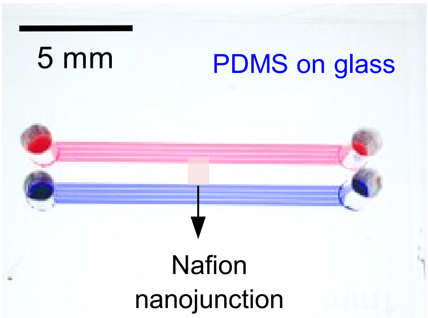

Fig. 2 Photograph of the micro-nanofluidic hybrid device. Microchannel was patterned on Si wafer and molded by PDMS. The anodic microchannel (red) connected to the cathodic microchannel (blue) by Nafion nanojunction.

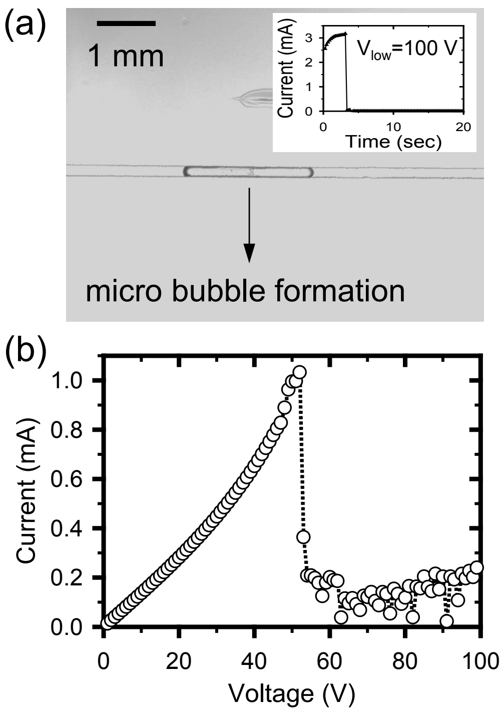

Fig. 3 (a) A micro bubble formation at the inside microchannel with an applied voltage (V_{low}=100 V, |E|=100 V/m). (b) Voltage condition for micro bubble formation. Channel was shorted at 53 V due to micro bubble formation.

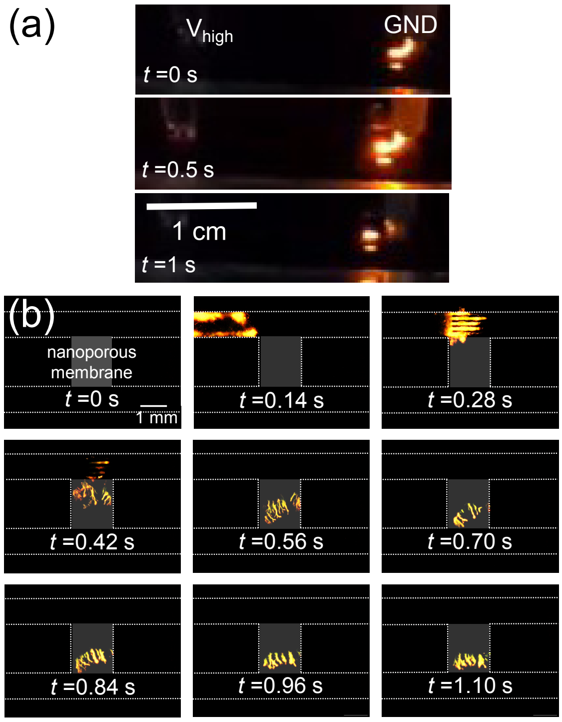

Fig. 4 (a) Plasma discharged at the inside microchannel with an applied voltage (V_{high}=500 V, |E|=500 V/m). Discharged bright was visibly observed along with the movement of bubbles. (b) The moment of plasma discharges inside the nanoporous membrane (t>0.42 sec).

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