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Review

Integrated fluidic systems on a nanometer scale and the study on behavior of liquids in small confinement

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ABSTRACT

Nanofluidic systems and the studies on the behavior of liquids confined in nanometer-sized space are reviewed. Miniaturized chemical systems having nanometer-sized structures are fabricated by using advanced nanofabrication techniques. The size-confinement effect is expected to be applied in well-controlled chemical and biochemical analysis. While electroosmosis and electrokinetic migration in small-sized channels have been investigated extensively, there have been few reports on pressure-driven flow systems having nanometer-sized structures, which are widely used in laboratory-scale and micrometer-sized systems. In this review, fundamental technologies that can be used in integrated chemical analysis systems having nanometer-sized structures are introduced. In addition to the technological investigations, important topics in the fundamental research on the properties of liquids confined in nanometer-sized space are also presented.

Contents

1. Introduction

Miniaturized chemical systems have attracted the attention of analytical chemists and engineers from various fields because of their useful features such as high throughput, compactness, labor saving, high reproducibility, and small sample requirement. Many review articles have been published on miniaturized systems and their applications [1–16]. One of the most important researches has been the developments of continuous flow chemical processing (CFCP) by utilizing microfluids in microchannels. In particular, the application of CFCP and micro-unit operations (MUOs) is expected to increase the integration density of microchips [17–20]. In order to realize higher integration density and to apply the size-confinement effect in chemical and biological analysis, techniques for fabricating smaller and thinner channels of the nanometer scale have to be developed. The applications and fundamental technologies of nanometer-sized channels, which are sometimes called as nanofluidic systems, have been discussed in recent review articles

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[21–26]. Most of these reviews have focused on the effects of well-defined geometry in separation science and specific electroosmotic transport phenomena.

From scientific viewpoint, nanometer-sized channels have attractive features. The size of tens or hundreds of nanometers is regarded as intermediate region between free bulk liquid and fully confined liquid in nanopores and mesopores. The thickness of an electric double layer in a dilute aqueous solution is comparable to the width and depth of a nanometer-sized channel. The specific surface of nanometer-sized channels is very large as compared to that of microchannels. Therefore, surface charges and chemical groups can affect liquid properties and solute behaviors significantly.

The width of a 100-nm-wide channel is comparable to the thickness of an electric double layer (Debye length) in a dilute aqueous solution. Effective surface chemical processes such as adsorption and reaction may take place on the surface of nanometer-sized channels because of their very high specific interfacial area. Furthermore, due to limited space, the reaction product may condense in the channels. Space restriction may affect the dynamics of biological macromolecules. By utilizing these features, novel separation, reaction, and assay are expected. However, sufficient information is not available on the fundamental properties of liquids confined in nanometer-sized space. Therefore, the fundamental properties of liquids confined in nanometer-sized space have to be experimentally elucidated.

Nanometer-sized channels have two distinguished characteristics. The first characteristic is the technological problem faced in controlling fluids flowing in nanometer-sized channels. As

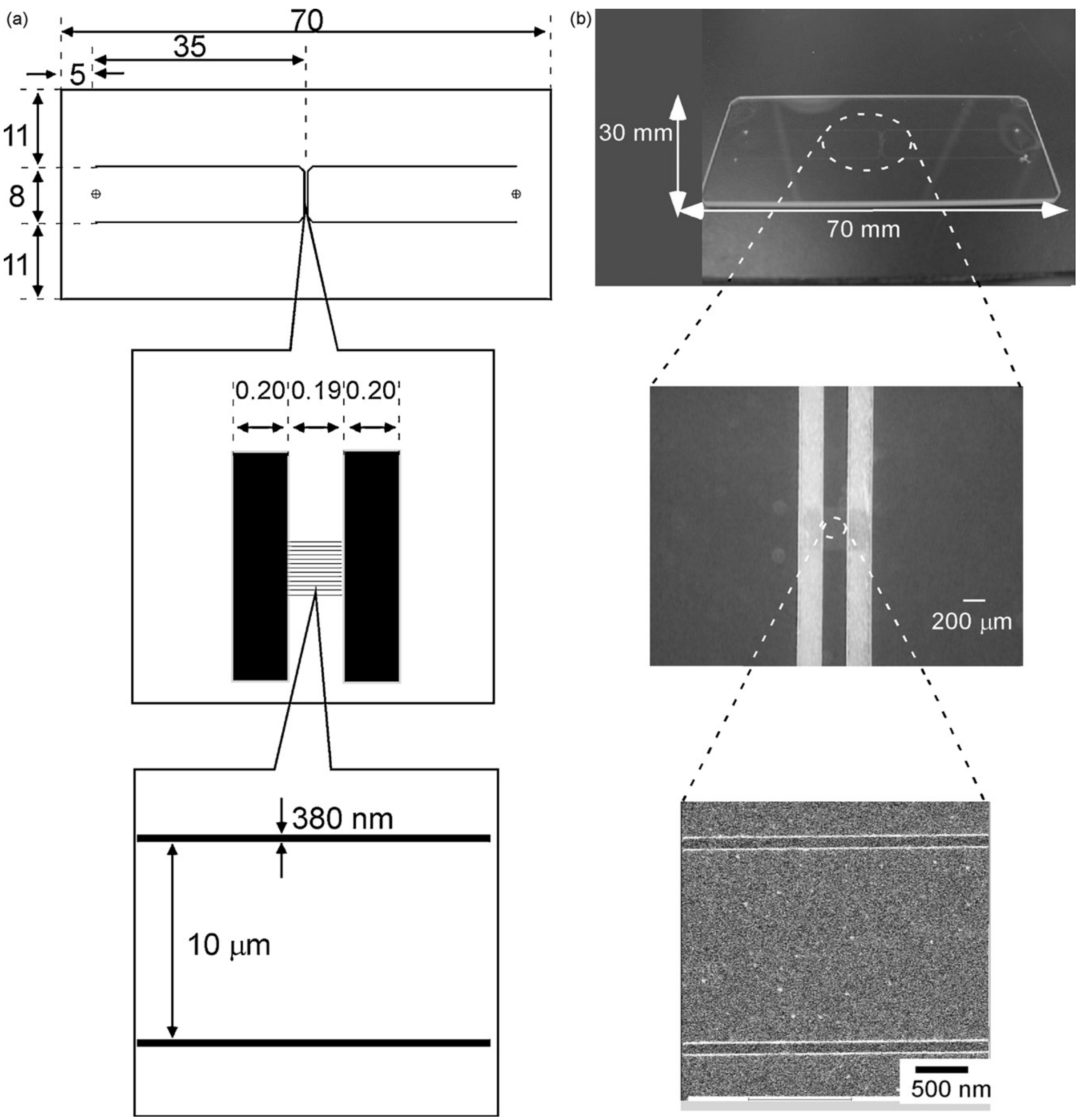

Fig. 1. (a) Example of channel layout. The input and output of the 380-nm-wide channels are connected to a 200-μm-wide channel. (b) Photograph, micrograph, and scanning electron microscope image of fabricated microchip. The depths of the nanometer-sized channels and the microchannel are 220 nm and 5.4 μm, respectively. From Ref. [33] with permission from Elsevier.