Micro-Fluidic Gate based on Photo-Rheological Fluid

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Keywords: photo-rheology, micro-fluidics

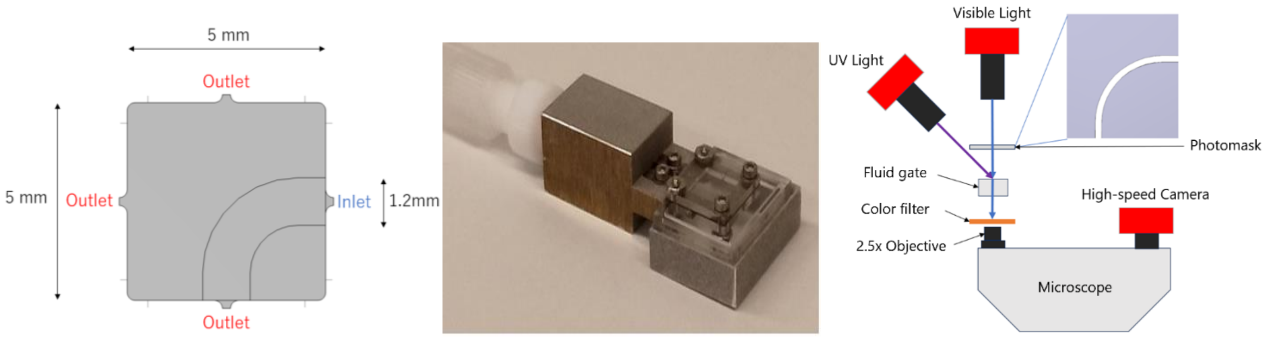
Photo-rheological fluids (PRF) have controllable viscosity as function of the wavelength of light with which they are irradiated. A light controlled micro-fluidic gate based on PRF is proposed and demonstrated, with 90% of the fluid exiting the intended outlet when the inlet flow is as high as 5 mm/s.

1. Introduction

Microfluidic systems control minute amounts of fluid in various applications including biochemistry, cell sorting, blood flow manipulation, and chemical synthesis [1]. Flow control can be achieved by varying the surface condition between hydrophobic and hydrophilic. Various methods have been used to create such surfaces, such as laser texturing, etching, or electrochemical processes [2], however this approach can only produce non-reconfigurable systems. The ability to dynamically control fluid flow through the application of an external force is thus desirable. Dielectrophoresis is a possible approach [3], although it requires imprinting electrodes on the surface which is time-consuming. Temperature control is another approach, in which a localized rise in temperature can cause fluid gelation [4] or convection [5] in some regions, around which the fluid is routed. However, the response time can be slow and the existence of temperature gradients renders fine control difficult. Instead, the use of photo-rheological fluids (PRF) based on light-sensitive cis-trans isomeric molecules is proposed here. The viscosity of a PRF can change reversibly depending on the wavelength of light irradiation. Hyuntaek et al [6] proposed inexpensive PRFs that can be made with commercially available components. It is proposed to use PRFs as microfluidic carrier fluid. By changing the viscosity in certain regions of the PRF, it is shown that the fluid flow direction can be affected with the fluid moving in the low-viscosity portion and stagnating in the high-viscosity portion.

2. Experimental Method

PRF was prepared by mixing pure water with 3.0 mM/L of ACA (azobenzene-4-carboxylic acid), 3.3 mM/L of NaOH, and 3.4 mM/L of Lipothoquad O/12 (di-POE(2) oleoyl methylammonium). Viscosity of the PRF under UV (365 nm) and visible (445 nm) irradiation was measured using a rheometer (HR10, TA). Next, a transparent fluid gate consisting of 1 inlet and 3 outlets, shown in Fig 1(a), was machined from an acrylic plate. The thickness of fluid between the bottom and top plate was set to 0.1mm, as shown in Fig 1(b), and the system was attached to a micro-syringe pump. The fluid gate was then installed into an experimental setup consisting of the 2 light sources and a photomask placed between the visible light source and gate. An inverted microscope with 2.5x objective and high-speed camera were used to record the motion of 10 µm glass beads (UVPMS-BG-1.00, Cospheric. Inc) suspended in the PRF. The OpenPIV software was used to analyze the motion of glass beads inside the microfluidic gate when UV only and UV+Visible irradiation is applied.



(a) Dimensions of fluid gate (b) Actual fluid gate (c) Experimental setup

Fig. 1. Design of fluid gate and experimental setup used for testing the photo-rheological fluid.

3. Results and Analysis

The results from Rheometer measurement are shown in Fig. 2. The viscosity quickly reduces as function of shear rate, reaching a condition similar to that of water around 30 s^{-1}. When the shear rate is low (1 s^{-1}), a noticeable difference is observed when the fluid is irradiated with UV only (32.4 mPa.s) and when it is irradiated with UV+Visible light (5.3 mPa.s). This means that the distribution of fluid viscosity can be controlled by using a single photomask to partially block the visible light, while simultaneously irradiating the entire area with UV. The results from particle image velocimetry (PIV) are shown in Fig. 3. When only UV irradiation is applied, the fluid flows generally from right to left, with a broadening of the flow region at the center of the gate. When an arc of visible light is applied between the inlet and the bottom outlet, the fluid instead flows preferentially between these 2 gates. The switch between the 2 states was found to occur within less than 1 second. For an inlet flow of 5 mm/s, over 90% of the fluid weas found to be exiting the cavity through the bottom outlet when irradiating with visible light.

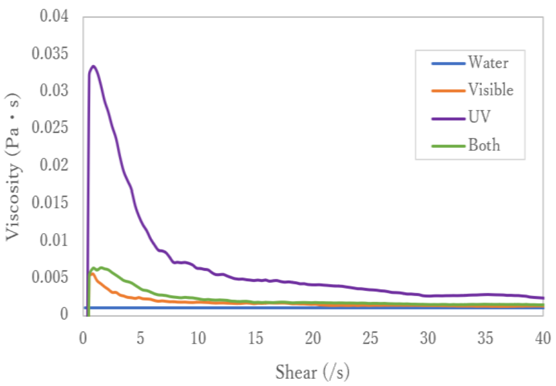


Fig. 2 Measured viscosity vs. shear rate

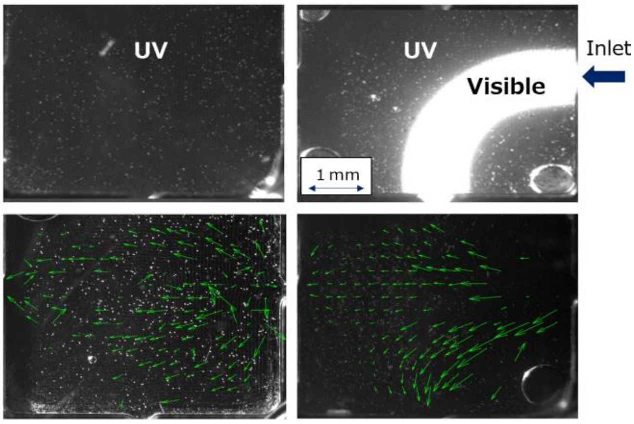


Fig. 3 Fluid flow under UV and UV/Visible irradiation

4. Summary and Outlook

The ability to control the direction of PRF fluid flow inside a micro-fluidic gate was demonstrated. A large change in viscosity was attained by irradiating the fluid inside gate with UV light and super-imposing a pattern of visible light passed through a photomask. The change in flow direction is rapid (less than a second) and reversible. Beyond the ability to control the flow of fluids in 2D to create fluid gates and separation devices, it is also expected that control of fluids in 3D should be possible by using a light-field based source of visible light [7]. It is expected that new types of micro-fluidic applications may become possible with 3D control of fluid flow, so this topic will be investigated in more details in future work.

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