Microfluidics as a tool for micro-manipulation

S Potgieter, K Land, R Sparrow

CSIR
Material Science and Manufacturing
Pretoria
South Africa

Summary

Microfluidics is a multi-disciplinary field that deals with the behaviour, control and manipulation of sub-millilitre fluid volumes. It is proving to be a useful tool for biological studies, affording advantages such as reduced cost, faster reaction times and process-specific designs. Another advantage of microfluidics is that micron-sizes particles can be manipulated with great precision. A microfluidic device is being designed to facilitate the sorting and self-assembly of components of a biological light-controlled nano-machine. This paper discusses the proposed design of the microfluidic device.

Introduction

Microfluidics is an emerging research area with specific applications in biomedical engineering and biotechnology. The advantages offered by microfluidics include reduced sample and reagent use, improved device efficiency, reduced cost, reduced reaction time, point-of-care possibility and process-specific designs (Nguyen & Wereley, 2006).

A microfluidic system typically consists of a series of channels with components such as pumps, valves, reservoirs and actuators to control the flow of fluids. These are combined to create lab-on-chip devices for performing chemical reactions or biological analysis (Liu et al. 2008; Nguyen & Wereley, 2006).

Some applications that have been miniaturised using microfluidics include DNA sequencing, polymerase chain reaction (PCR), electrophoresis, DNA separation, immunoassays, cell counting and cell culture (Sia & Whitesides, 2003).

This paper describes the initial steps in designing a device to assemble nano-machines that convert light energy into mechanical movement. Due to their small size, handling the components and fabricating the devices is a challenging task. A further complication is that the components are required in specified numbers and an established sequence. Self-assembly combined with microfluidics is a promising way to overcome these difficulties.

The concept of self-assembly has been proven by several groups (Chung et al. 2008, Wu et al. 2008). It involves the joining of two or more entities in a thermodynamically stable arrangement (Dagani et al. 2007). The advantage of self-assembly is that a desired set-up is achieved without the need to manipulate the components individually.

The nano-machines make use of a light-harvesting array for energy collection. The light-harvesting array consists of light-harvesting complexes (LHC) composed of chlorophyll pigments. These complexes have to be grouped closely together for energy transfer to occur.

Lipid-based vesicles, originally called Emzaloids and now Pheroids™, were manufactured that spontaneously incorporate LHC. The typical size distribution of the Pheroids™ is around 1 µm in diameter. They need to be sorted, isolated and brought into contact with a specified number of LHC for incorporation. The proposed method to accomplish this is via a microfluidic device.

Materials and Methods

Microfluidic channels will be fabricated from poly(dimethylsiloxane) (PDMS). PDMS is an elastomer which is inexpensive, biologically compatible, permeable to gas and easy to fabricate (Duffy et al. 1998; Sia & Whitesides, 2003). Soft lithography will be used for manufacturing the channels. This describes a group of methods in which a master, or mould, containing the desired channel structure, exists (Xia & Whitesides, 1998).

PDMS (Dow Corning Sylgard 184) will be poured into the moulds and cured to create the flow channels. Channel dimensions in the order of 100 µm deep and 100 µm wide will be used initially. To visualise particle flow in the channel, a thin (in the order of 100 µm), rigid base is required. Different base options will be investigated to optimise the image resolution, including glass and polycarbonate. Syringe needles are used for introduction and removal of fluid from the channel, see Figure 1.

The Pheroids™ are manufactured from a patented process at the University of North-West, South Africa. They were initially used as a drug delivery system (Saunders et al. 1999), consist of a lipid membrane and have a diameter of about 1 µm. They are very stable and, as stated, have been shown to spontaneously incorporate LHC. The viability of the LHC after incorporation has not been established, and will be part of the investigation.

Particle flow is of great importance. In order to accurately assemble the machine, components need to be moved and counted in the microfluidic channels. This requires characterisation and precise control of particle flow. There is a potential difference between the inside and outside of the Pheroid™ membranes. The effect this will have on the particle flow is not known, and will be investigated.

The microfluidic device will need several compartments. These include two reservoirs containing the Pheroids™ and LHC, an incorporation region (which might include a mixing mechanism) and a storage area where the assembled products are stored. Each of these compartments will have to be sealed off with a valve to ensure only the desired number of particles is allowed to interact. A sensor will be necessary at the inlets to the incorporation compartment to allow only the desired number of particles to enter. A schematic of the proposed device is shown in Figure 2.

The Pheroids™ will flow from a reservoir to the incorporation area, where they can be brought into contact with a specified number of LHC. Enough time must be

allowed to ensure complete incorporation of all LHC into the Pheroid™. The filled Pheroid™ must then be moved to a storage area, while a new Pheroid™ enters the incorporation area.

The assembled Pheroid™, containing a specified number of LHC, will act as the "battery" for the nano-machine. From here, the light-activated proton-pump mechanism will be used to convert photons of light into ATP, an energy form accessible to living organisms.

Conclusion

A microfluidic device is being designed to facilitate the assembly of the components of a biological light-driven nano-machine. The proposed design has been shown and several areas that need to be investigated further have been highlighted. The final product will convert photons of light into the biological energy currency, ATP. Several further designs exist to utilise this energy source for mechanical movement, an artificial retina or even an artificial neuromuscular junction. Microfluidics is a promising alternative to a future of clean, renewable energy sources.

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The Pheroids™ used in this study will be manufactured at the University of North-West, South Africa.

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