An interdisciplinary approach

Optofluidics brings together light and liquids to provide technologies such as fluid waveguides, deformable lenses and microdroplet lasers. *Nature Photonics* spoke to Frances Ligler about the origins of the field and where it might be heading.

What is optofluidics?

There are many different definitions, but my contention is that 'optofluidics' is the integration of optics and fluidics to provide capabilities that cannot be achieved through either field alone. Optofluidics is more than just a system that exploits both optics and fluidics; they work in tandem to enhance each other. Although the term 'optofluidics' has only been used for seven years or so, the field has been around in one form or another for quite some time, and you can find many examples that predate the use of the term. Some of the older examples include liquid-core waveguides and deformable gratings and lenses. I had a patent in 2000 that used a capillary as both a flow guide and a waveguide. In the 1980s, researchers in the fibre-optic sensor community used optics to release reagents into solutions. These types of demonstrations set the stage for the field we now refer to as optofluidics. The term 'optofluidics' became popular around the time that researchers working on microfluidics began to think more about what could be accomplished by integrating microfluidics with optical and electrical systems. Optofluidics really took off with the rapid microfluidic structure prototyping capabilities pioneered by George Whitesides, who used the organic polymer polydimethylsiloxane (PDMS) as an alternative to more standard silicon and glass technologies.

Why did you become interested in optofluidics?

I was convinced that the ability to make prototype systems in plastics would allow us to move from stacked two-dimensional systems to truly three-dimensional devices; it was three-dimensionality that first attracted me to microfluidics. Many of the advances in optofluidics have taken advantage of the ability to configure structures in three dimensions. For example, we can put optical signals into a non-solid system without connectors. There are many things we can do now that were inconceivable ten years ago. Today we can use fluidics to refocus lenses in real-time, create optical tweezers to manipulate cells and particles, and make microdroplets lase. There is also some interesting research into the development of optical pumps and values — an area that should gather significant attention in the future. Such devices would be extremely useful as there are currently very few options for mechanical microfluidic pumps and valves. Only now are we seeing the application of optofluidics to photonic crystals, and this is an area that may grow faster for photonic applications than sensing.

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Frances Ligler is currently the US Navy's senior scientist for biosensors and biomaterials. She works on microfluidics and systems integration, mostly for optical biosensors, and has been with the US Navy for 26 years.

What are some of the main hurdles to overcome?

You need to use water if you are going to interrogate biological systems. Biological and chemical analyses are frequently performed in aqueous solutions, which have low refractive index. The refractive index can be increased to a certain extent by using benign additives such as sucrose, but living cells will not be very happy if you change the osmotic conditions too much. These limitations do not exist for photonic applications, thus allowing a much wider variety of non-solid materials with varied refractive index to be used. There are also limitations in terms of the delivery and control of liquids in micro- and nanosystems. However, the manipulation of liquids inside a photonic window may lead to new technology that does not require the sample to be transported to the biological or chemical analysis system.

Another limitation is the material used for the solid part of an optofluidic system. Many of the plastics used for microfluidic fabrication are fluorescent or scatter light. Researchers are now thinking more about the optical properties of the materials used for the fabrication of these systems. Many are demanding well-characterized materials — in terms of both optical properties and chemical stability — to be made available for microfabrication. We certainly want to move away from PDMS. Researchers are looking at cyclic olefin copolymer (COC), poly(methyl methacrylate) (PMMA), polystyrene and other materials. Advances in material sophistication will allow us to do more with optofluidic systems. Most researchers start out by using PDMS for rapid prototyping, but then move onto materials that can be injection-moulded or formatted using hot embossing, as these are more suited to mass-manufacturing than PDMS.

What might the future bring?

I am very interested in the Review on optofluidics for energy applications in this Focus Issue of *Nature Photonics*. One question is whether optofluidic systems can be used on-chip to provide energy for very small systems, or even with *in vivo* medical devices. Another interesting area is the use of optofluidics to eliminate the need for optical connections, whether for remote sensing or for solving the major problem of connectivity in integrated devices. A further opportunity is micro- and nanomanufacturing, but the use of optofluidics here is still in its infancy. Bringing the analytical tools the sample, instead of vice versa, is another interesting research area. Optofluidics is a field in which it is absolutely essential for engineers and scientists from different communities to collaborate, not only to understand how optics and fluids interact but also to understand what applications and capabilities may be possible.

INTERVIEW BY DAVID PILE