Development of a Miniaturized Liquid Core Waveguide System With Nanoporous Dielectric Cladding—A Potential Biosensing Platform

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***Abstract*—We present a high-throughput optofluidic light waveguide system consisting of etched microchannels in silicon using water as the core and an ultra low refractive index nanoporous dielectric (ND) as the cladding Organosilicate nanoparticulate films with refractive index of 1.16 have been used as the cladding layer. Although NDs offers many advantages over Teflon AF for use as the cladding layer, integration of these coatings to the waveguide design is not trivial. In this paper, we address the various integration issues of the NDs to the liquid core waveguide architecture followed by testing of these waveguides for their light guiding capability. Compared to uncoated channels, ND clad channels offer a high light guiding efficiency. In addition, the high surface areas associated with them could be potentially used to immobilize higher density of sensor probes implying a great potential for biosensor applications in an integrated system.**

***Index Terms*—Liquid core waveguides (LCWs), nanoporous dielectrics (NDs), optofluidic systems.**

I. Introduction

RESEARCH and development of highly target-specific sensors have attained a level of paramount importance because of the burgeoning need for applications in national security [1]–[3], health care, the environment, and food safety [4]–[8]. Fluorescence-based sensing is among the most commonly used transduction methods for these applications and these are typically performed in water as it is the natural medium for biological processes. There is a growing demand for miniaturization of these systems for point of care applications. In addition to the reduced costs, lower sample volumes are required in miniaturized microfluidic systems, and with the recent technological advances in the field of optoelectronics, optical interrogation and detection units could be readily integrated into these platforms [9]. One way of increasing sensitivity of detection of these systems is by confining and guiding most of the fluorescent light through the microfluidic pathway to the detection unit. Thus, using the same microchannels for the fluidics as well as waveguiding greatly simplifies the design complexity of these systems while minimizing light loss through the channel walls. These microfluidic pathways are termed liquid core waveguides (LCWs) [10], [11]. Guiding of light through a waveguide could be accomplished in a variety of ways. The most common waveguide architectures rely on total internal reflection (TIR) for light guiding. These waveguides are comprised of a higher refractive index core material surrounded by a lower refractive index cladding wherein light gets guided in the core through TIR. Construction of a TIR-based LCW with water as a core however poses its own unique problem. Water has a refractive index of 1.33, considerably lower than most readily available materials. This places a serious constraint on the choice of cladding material to be used for the construction of these waveguides.

With the development of polymeric materials of the class polytetrafluoroethylene (PTFE)—type Teflon and amorphous Fluoropolymer (Teflon AF 2400), materials with refractive indexes lower than water has been made commercially available. Teflon AF 2400 has been reported to have a refractive index of $n = 1.29$ [12] which was the lowest reported refractive index for any known polymer. Teflon AF tubes and Teflon AF coated glass capillaries are now commercially available and have been widely exploited for use as long path length LCWs for absorption [13], fluorescence [14], and Raman spectroscopy [15]. Our group reported the first miniaturized LCWs employing Teflon AF as cladding [10], [11].

Although Teflon has established itself as a versatile material for LCW design, it is not the ideal choice. Teflon being extremely inert makes it difficult to chemically functionalize its surface. It has poor adhesion to common substrates and its extreme hydrophobicity makes it difficult to fill microchannels with water. In addition, the refractive index contrast between Teflon and water is at most 0.04 which translates to an acceptance angle of only 18° [16]. For applications in fluorescence and Raman-based sensors, this poses a major limitation. As the fluorescence is generated isotropically within the waveguide, it is advantageous for the waveguide to have a large acceptance

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