Integrated Photonics for Bioanalytical Microsystems

James S. Wilkinson
Optoelectronics Research Centre, University of Southampton, Highfield, Southampton, SO17 1BJ, UK
jsw@orc.soton.ac.uk

Abstract: The motivation, progress and potential of optical waveguide integration into microsystems for bioanalysis will be discussed.

Demand for rapid, low-cost biochemical analysis exists in a multiplicity of applications, including food safety, water quality, personal and preventative medicine, pharmacogenetics and point-of-care diagnostics. The ideal lab-on-chip (LoC) device to fulfil this demand would combine microfluidics with integrated spectroscopic or assay methods on a common platform and automate the analytical procedure. Critically, it would also be mass-producible and operable by a non-expert user. Optical techniques play a major role in quantitative chemical analysis and remain the mainstay of detection in LoC systems, but the degree of optical functionality integrated within these systems remains limited, comprising separate components rather than an integrated whole.

Integrated optical waveguides enable low-cost mass-production of compact, robust, bioanalysis chips, and are ideal for the integration of optical functions in microsystems. The fabrication techniques which revolutionised electronics enable a similar transformation in guided-wave photonics, and the resulting optical circuits are particularly well suited to mass-produced bio/chemical sensor arrays exploiting chemical reactions at surfaces [1]. Many integrated optical devices have seen success in telecommunications systems and this has led to a sophisticated "toolkit" of integrated components for building planar lightwave circuits (PLC's) [2]. Planar lightwave circuits are realized by combining photolithographic patterning and etching with the deposition of dielectric films onto surfaces or the diffusion of dopants into surfaces, and are thus inherently complementary to microfluidic and microelectronic systems. The use of the mass-production techniques developed for microelectronics in the production of integrated optical devices brings low cost, and the micron-scale replication technology allows miniaturization and dense integration. In the case of surface sensing, integrated optical waveguides provide a strong and well-controlled evanescent interaction of light with chemical species at a surface in a very small sample volume, allow integration of reference sensors and arrays of sensors measuring different parameters on the same chip, can integrate metallic or transparent electrodes for electrochemical monitoring or reaction control [3], may probe a wide range of optical phenomena, and are compatible with optical fibre for direct connection to instrumentation. Appropriately designed monomode optical waveguides offer the ultimate sensitivity for evanescent spectroscopy and sensing. However, integrated photonic technologies for telecommunications operate in the visible and near infra-red (NIR) wavelength region from 0.4 μm – 2 μm. While these wavelengths are routinely used for biosensing, the molecular "fingerprint" region is dominated by the mid infra-red (MIR) spectral region from 2 μm – 15 μm. Quantifying molecular vibrations and transitions in the MIR region potentially allows the direct identification of a target without the need for functionalised surfaces or fluorescent labeling, and an integrated photonic platform that can operate over both the NIR and MIR spectral ranges is much needed [4]. In applications where the volume of a liquid or of a micron-scale object such as a biological cell is to be interrogated, non-evanescent in-plane optofluidic approaches must be adopted. In this case a key exemplar component is the in-plane lens [5], which can be used for trapping, scattering, fluorescence or Raman measurements. Recently, interest has grown in optical manipulation at surfaces [6] as a potential part of the toolbox of the "lab-on-a-chip" to complement sensing and detection. In particular, advances have been made in trapping and propulsion of biological cells in the evanescent fields of optical waveguides, which may form part of a microsystem into which optical detection and spectroscopy of separated species could also be integrated [7]. Optical waveguides embedded in surfaces are a powerful way of controlling the distribution of optical intensity and intensity gradient at such surfaces for such particle control.

In this paper, advances in optical waveguide devices for biosensing, cell manipulation, microcytometry and mid-IR spectroscopy will be described.

This work is funded by the European Research Council (ERC), part of the European Union Seventh Framework Programme (FP7), under grant agreement no. 291216 (WIPFAB).

[1] P. Hua, J.P. Hole, J.S. Wilkinson, G. Proll, J. Tschemelak, G. Gauglitz, M.A. Jackson, R. Nudd, H.M.T. Griffith, R. Abuknesha, J. Kaiser & P. Kraemmer, Optics Express **13** 1124-1130 (2005).
[2] C.R. Doerr & K. Okamoto, J. Lightwave Technology **24** 4763-4789 (2006).
[3] J.C. Abanulo, R.D. Harris, A.K. Sheridan, P.N. Bartlett & J.S. Wilkinson, Faraday Discussions **121** 139-152 (2002).
[4] J.J. Hu, V. Tarasov, A. Agarwal, L. Kimerling, N. Carlie, L. Petit, & K. Richardson, Optics Express **15** 2307-2314 (2007).
[5] H.C. Hunt & J.S. Wilkinson, Optics Express, **20** 9442-57 (2012).
[6] S. Kawata & T. Tani, Optics Letters **21** 1768 -1770 (1996).
[7] O.G. Hellesø, P. Lovhaugen, A.Z. Subramanian, J.S. Wilkinson & B.S. Ahluwalia, Lab Chip, **12** 3436-3440 (2012).