Arrayed-waveguide-grating light collector for on-chip spectroscopy

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Abstract—**We present a novel arrayed-waveguide-grating (AWG) device with improved external (biomedical) signal collection for use in on-chip spectroscopy. The collection efficiency of the device is compared to that of a standard AWG. We also present experimental results on the collection efficiency and size of the collection volume.**

Keywords-arrayed waveguide grating; spectroscopy; integrated optics

I. INTRODUCTION

Large efforts are currently being made to miniaturize optical devices, as for example integration of OCT systems and Raman spectrometers [1, 2]. In this work we draw the attention on on-chip spectrometers, in particular on the issues related to focusing light from the on-chip excitation laser source into the (biomedical) sample under study, and collection of the light backscattered from the sample. We propose a novel method for laser delivery and signal collection based entirely on integrated optics, and we present our first experimental results on the collection efficiency and the size of the collection volume.

II. LASER DELIVERY AND SIGNAL COLLECTION

A. Method description

The proposed method [3] makes use of two AWG devices (for the working principle of an AWG we refer to the work of M. K. Smit and C. V. Dam [4]), one for focusing the excitation beam into the sample and one for collecting the backscattered light from the focal spot. The devices are arranged in such a way that the output grating line of the focusing device, which lays on a circle, is concentric with the input grating line of the collection device. In this way the output free propagation region (FPR) of the excitation device and the input FPR of the collector device merge together forming a single free propagation region that for convenience we indicate with SFPR (sample-side FPR). The length of the SFPR region must be chosen in such a way that when brought in contact with the sample the focal spot is located inside the latter at the desired depth *d* (this choice depends on the refractive index of the sample). Figure 1 shows a schematic of the two devices where, for simplicity, the excitation device and the collection device have a single channel. In the most general case both devices may present more than one channel. In particular, if we are interested in performing spectroscopic measurements on the sample, the collection AWG must be designed with the appropriate number of output channels depending on the desired wavelength spacing and free spectral range (FSR) needed for the application.

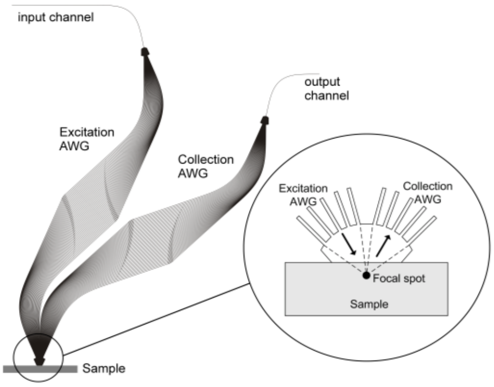

Figure 1. Schematic of the laser delivery and signal collection device with a single input and a single output channel. The inset shows the confocal arrangement of the two devices.

B. Collection efficiency

We have compared the collection efficiencies of two similar AWGs; the first is a standard AWG (the reference device) with an input FPR region of length l_{FPR} and an input channel which collects the light, whilst the other (corresponding to the collection AWG of the device proposed above) presents only part of the input FPR of length $l = l_{\mathrm{FPR}} - d$ (its length l depends on the distance d from the source) and no input channel, i.e., light collection is made by the SFPR. For the characterization, both devices are placed at a distance d from a light source S. A schematic representation of the input sections of the two devices is shown in Fig. 2.

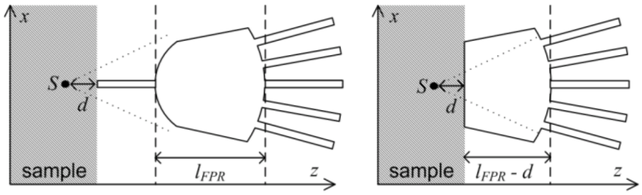

Figure 2. Input sections of a standard AWG (reference device, left-hand side) and an arrayed-waveguide-grating collector (proposed device, right-hand side) positioned at a distance *d* from a source *S*.

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The collection efficiency of both devices was calculated analytically as a function of *d*, using the following parameters: monochromatic source emitting at wavelength λ = 1284.6 nm with a numerical aperture of NA = 0.16; sample refractive index of 1.46; device geometry and waveguide cross-sections as described in SECTION III. All chosen parameters correspond to those used in the experimental setup. The simulation results are shown in Fig. 3. In all the simulations the number of arrayed waveguides *N* is constant (*N* = 400) and the AWG spillover losses are around 0.05% for NA = 0.16. On the secondary axis of Fig. 3 we show the gain in collection efficiency achieved using our proposed device compared to the reference device as a function of *d*, for different values of NA. As *d* increases, the collection efficiency of the collector AWG increases compared to that of the standard AWG, becoming approximately 10 times larger than for the standard AWG for *d* = 225 μm. In order to simulate the more realistic situation in which light inside a sample is scattered in all directions, i.e., approaching a point source, we calculated the efficiency also for higher NA values of the source. We notice that for NA ≥ 0.35 there is no significant increase in the efficiency, which starts to drop for NA ≥ 0.55. This is due to an increase in the spillover losses as the emission angle of the source becomes larger. To overcome this problem the number of arrayed waveguides should be accordingly increased. We have calculated that for an ideal situation in which light is emitted over the whole solid angle, and where the number of arrayed waveguides is sufficient to capture all the light coupled into the input FPR, the power collected by the collector AWG would be around 30 times higher than that collected by the reference device already at a distance *d* = 100 μm.

III. EXPERIMENTAL RESULTS

Measurements were performed on two identical AWG devices fabricated in silicon oxynitride (SiON) technology [5] with a waveguide cross section of 2 μm × 0.6 μm and SiO_2 cladding. The core and cladding refractive indices were 1.55 and 1.4485, respectively, at 1.3 μm. The length of the FPR was 5393.5 μm, the number of arrayed waveguides 400, and the central wavelength 1.3 μm. Furthermore, the AWGs presented 100 output channels with a wavelength spacing of 0.38 nm. In order to perform the measurements for varying distance *d*, the free propagation region of the proposed AWG collector was diced for each measurement point. The dicing was performed using a 30-μm-thick diamond blade. As a source we used a tunable diode laser (New Focus 6324) at a wavelength of 1284.6 nm connected to a single-mode optical fiber with NA = 0.16. Index matching liquid with a refractive index of 1.46 was used between the source and the device. For accurate positioning of the source fiber a motion controller (Newport PM500) was used, which allows for a stable position at variable distance from the chip with nanometer precision. For each position *d* the output power was measured with a power sensor (HP 8153A) for both devices from the output channel centered at 1284.6 nm. The measurements, displayed in Fig. 3, are in good agreement with the simulation results. In order to determine the size of the region within the sample from which light is collected using the AWG collector, we moved the fiber (originally centered on the focal point) in the three spatial directions while keeping the excitation wavelength fixed. By taking the points where the power decays by 3 dB (see Fig. 4), we calculated a volume $\Delta x \Delta y \Delta z$ of 4.4 μm × 35 μm × 65.5 μm for a distance *d* of 224 μm. For *d* = 36 μm we measured Δx = 4.4 μm, and Δy = 5 μm (we were not able to perform the measurement of Δz for this distance).

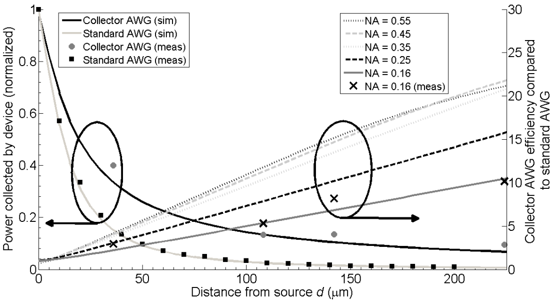

Figure 3. (primary axis) Simulation and measurement results showing the power collected by the AWG collector compared to that of the reference device as a function of the distance *d* from the source. The results are normalized to the collection of the reference device at *d* = 0. (secondary axis) Collected power ratio between the proposed AWG and the reference device as a function of *d*, for different values of NA.

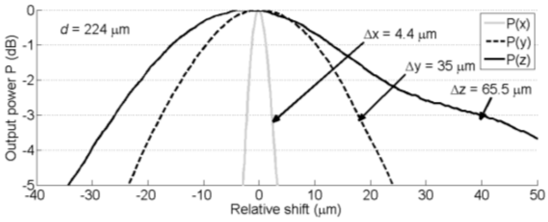

Figure 4. Measurement of the collection volume of the arrayed-waveguide-grating collector for *d* = 224 μm.

IV. CONCLUSIONS

We presented a method for focusing and collecting light from a sample, which makes use of two AWG devices in a confocal arrangement. This opens possibilities for on-chip spectroscopic measurements with no need for external optics. Our experimental and simulation results on the collection efficiency of the device showed that it can be up to 20 times higher than that achieved using an input waveguide channel connected to a standard AWG device.

V. REFERENCES

[1] E. N. Lewis, P. J. Treado, and I. W. Levin, "A Miniaturized, No-Moving-Parts Raman Spectrometer," *J. Appl. Spectrosc.* vol. 47, pp. 539-543, 1993.

[2] G. Yurtsever and R. Baets, "Towards integrated optical coherence tomography systems on silicon on insulator," in *Proc. Symp. IEEE/ LEOS Benelux Chapter*, Enschede, The Netherlands, 2008, pp. 163-166.

[3] N. Ismail, M. Pollnau, and A. Driessen, "Scattered light collector, light focusing apparatus, method for controlling the focus of a focused light source and method for measuring the light scattered or originating from a point of an object." Patent No. NL 1036920, The Netherlands, 2009.

[4] M. K. Smit and C. v. Dam, "PHASAR-Based WDM-Devices: Principles, Design and Applications," *J. Select. Topics Quantum Electron.*, vol. 2, pp. 236-250, 1996.

[5] K. Wörhoff, L. T. H. Hilderink, A. Driessen, and P. V. Lambeck, "Silicon oxynitride: a versatile material for integrated optics application," *J. Electrochem. Soc.*, vol. 149, pp. 85-91, 2002.