OPTIMIZATION OF SIGNAL-TO-NOISE RATIO IN ABSORBANCE DETECTION BY INTEGRATION OF MICROOPTICAL COMPONENTS

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Abstract
Measurements of light absorbance is an important and versatile detection method for microanalytical systems. Limitations with respect to sensitivity are based on the short optical pathlengths and the relatively small amount of optical power coupled into the fluidic channels. In-plane detection cells with integrated waveguides can alleviate the pathlength issue, while geometrical shaping of the waveguide-channel interface including tapers and lenses can help increase the amount of optical power that can be utilized for measurements. A simple analytical model is compared to experimental data demonstrating the optimization of signal-to-noise ratios as a function of pathlength using different integrated collimator and lens structures.

Keywords: absorbance detection, microoptics, polymer waveguides, signal-to-noise ratio

1. Introduction

Studies of absorbance detection in microfluidic systems have so far been focused on increasing the optical path length in order to improve the sensitivity [1, 2]. However, the important parameter for detection of low sample concentrations is not the sensitivity, but the signal-to-noise ratio (S/N). In this study, the influence of the optical path length on the S/N is investigated. Integrated planar waveguides are used in order to avoid having a path length that is limited by the channel depth. Microoptical components, such as 2D planar lenses and collimators are furthermore integrated in order to improve the coupling efficiency over the fluidic channel (see Fig. 1). The experimentally obtained S/N data are compared to an analytical model.

2. Theory

By differentiating Lambert-Beer's law, $A = \log(I_0/I)$, with respect to the light intensities (I_0, I), a relation between the variance of the baseline measured in absorbance units (ΔA) and the variance in the light intensity (ΔI) can be obtained

7th International Conference on Miniaturized Chemical and Biochemical Analysis Systems
October 5–9, 2003, Squaw Valley, California USA

[3]:

$$\Delta A = \frac{1}{\ln 10}\sqrt{\left(\frac{\Delta I}{I}\right)^2 + \left(\frac{\Delta I_0}{I_0}\right)^2}. \qquad (1)$$

The ratio $A/\Delta A$ is then given by (in the limit $I \ll I_0$):

$$\frac{A}{\Delta A} = abc \ln 10 \frac{I}{\Delta I}, \qquad (2)$$

with a=molar absorptivity, b=pathlength, c=analyte concentration.

Since equation 2 is derived from Lambert-Beer's law it is expected that $S/N \approx A/\Delta A$ (see section 4). From equation 2 it is seen that a reduction in the relative error of the measured light intensity ($\Delta I/I$) is equally important as an increase in the sensitivity (ab) in terms of S/N. An improved sensitivity is often achieved by increasing the optical pathlength, albeit at the cost of a lower transmitted power. This means that at a certain point a further increase of the sensitivity is accompanied by a reduction of the signal-to-noise ratio (section 4).

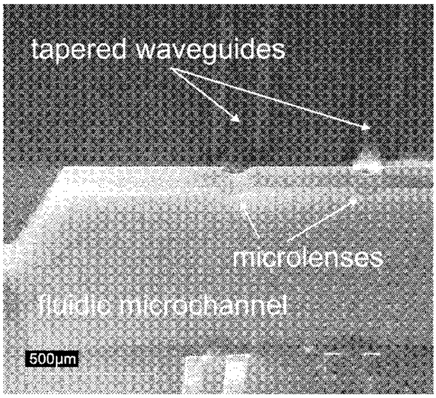

Figure 1: SEM picture of a microstructure for S/N measurements fabricated by structuring a single SU-8 layer.

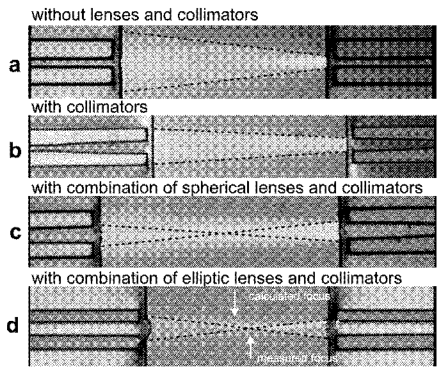

Figure 2: Emission patterns for (a) wave guides without lenses and tapers, (b) tapered waveguides, (c) waveguides with tapers and spherical lenses and (d) waveguides with tapers and elliptical lenses.

3. Experimental

All structures including integrated lenses and tapers were made by a one-step lithography process in the photoresist SU-8 [4]. Fig. 2 shows the emission patterns from different configurations of lenses and tapers (collimators) at the waveguide-channel intersection. The dotted lines indicate the angle of emission for the major fraction (90%) of the light. The effect of the microoptical components on the coupling efficiency was determined by measuring the coupling loss for channel widths between 100 μm and 4000 μm (Fig. 3).

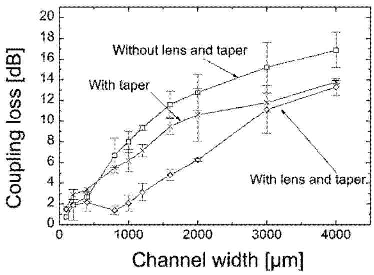

Figure 3: Coupling loss as a function of optical path length for different configurations of beam shaping components (the connecting lines are for guidance only).

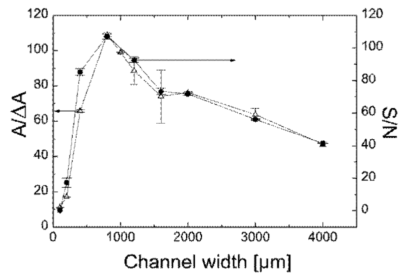

Figure 4: Verification of the relation $S/N \approx A/\Delta A$ (open symbols: $A/\Delta A$, filled symbols: S/N).

4. Results and discussion

A comparison of Fig. 2a (straight waveguide) and Fig. 2b (tapered waveguide) shows that tapering results in a reduction of the emission angle. Focusing of light with the use of a spherical lens (Fig. 2c) and an elliptical lens (Fig. 2d), respectively, was also investigated. The beam shaping properties of the various lenses and tapers are presently investigated in more detail.

The coupling losses (α) across the channels were calculated from the relation, $\alpha = -10\log(I_{\text{channel}}/I_{\text{reference}})$. It can be seen that the coupling losses of structures with tapers and lenses are on average reduced by 3 dB compared to structures without any beam shaping (Fig. 3). This corresponds to a doubling of the transmitted optical power.

The S/N as a function of the optical path length for a 50 μM concentration of bromothymol blue at 635 nm was calculated by dividing the absorbance value, $A = log(I_0/I)$, with the measured standard deviation of the baseline signal (Fig. 4). There is a maximum at around a pathlength of 1000 μm. The relation ($S/N \approx$

$A/\Delta A$) was investigated by also plotting $A/\Delta A$ given by equation (2) into Fig. 4. The two graphs are basically identical, qualitatively as well as quantitatively. It should be noted, however, that the datasets from which these two graphs were obtained are not identical. The S/N requires two measurements (I, I_0), while calculation of $A/\Delta A$ (eq. 2) only requires the measurement of I. Further investigations are currenly made on the limit of detection (for the case $I \approx I_0$). This formalism can be extended to predict the corresponding curves, when, e.g., the coupling loss is reduced by inclusion of focusing elements (Fig. 3). In this case it is expected that the maximum is shifted to higher values of both, b, and S/N. Both mentioned issues are currently under further investigation.

5: Conclusions

The influence of microoptical components on the coupling loss was investigated. It was shown that a structure with integrated lenses and tapers corresponds in average to a doubling of the transmitted optical power. A maximum for the signal-to-noise ratio around an optical pathlength of 1000 μm was observed. A simple theoretical model based on Lambert-Beer's law was used to explain this behavior.

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