Increased response of trap detectors with apertures due to nitrogen flow

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According to our experimental results and simulations, a nitrogen flow used to prevent dust and moisture entering the detector may influence measurements performed with trap detectors in overfilled conditions. Based on simulations, the nitrogen flow through the detector forms a nitrogen beam that might act as a gradient-index lens increasing the effective aperture area of the detector and thus the photocurrent. The turbulence of the flow increases standard deviation of the measurements. The shape of the nitrogen beam depends on the size of the limiting aperture of the detector. Thus, the maximum usable nitrogen flow should be determined separately for each configuration.

INTRODUCTION

Measurements using trap detectors are carried out daily in optical metrology. Typically, the photodiodes in the detector are exposed to ambient conditions of the laboratory. Dust and moisture accumulating on the diodes increases the uncertainty of the measurements and reduces the calibration interval.

A nitrogen flow system can be used to prevent the moisture and dust collection on the diodes [1]. A constant flow of dry nitrogen is introduced through the detector, where it exits the detector aperture preventing unwanted particles and moisture entering the detector. The optical properties of nitrogen are rather similar to those of air. Based on this, the flow should tentatively not introduce any errors into the measurements. However, our results indicate that the nitrogen flow can increase signals in overfilled measurement conditions.

RESPONSIVITY MEASUREMENTS

In our measurements of a 5-cm diameter LED source at the distance of 4.5 m using methods presented in [2], we have noticed that the nitrogen flow influences the results. Measurements were carried out with a wedged trap detector of two photodiodes and a precision aperture with a diameter of 4 mm. Figure 1 presents the normalized photocurrents from the trap detector at nitrogen flow rates of 0.5 – 2.0 l/min. The standard deviations of the results are also indicated. It can be noticed that with flow rates of 1.0 and 1.5 l/min, both the photocurrent and the standard deviation are clearly elevated when compared to the results at the flow rate of 0.5 l/min.

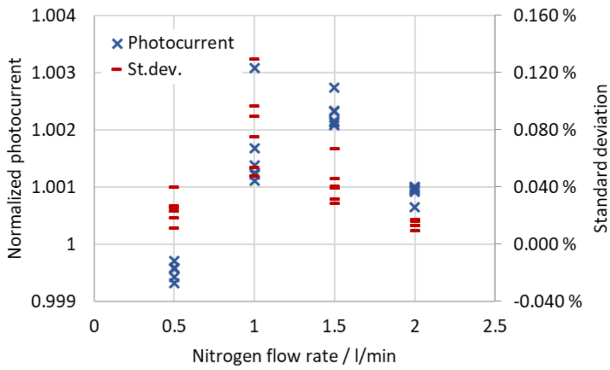

Figure 1. Relative photocurrents and their standard deviations of 6 measurements using stable white LED source with a trap detector and a 4-mm diameter limiting aperture in overfilled condition (>100 × d_{aperture}).

Measurements were also carried out for the responsivity in underfilled mode utilizing different flow rates. The normalized results are shown in Figure 2, where it can be seen that the changes in responsivity are approximately two orders of magnitude smaller than the changes in the measurements made in the overfilled mode. These results link the responsivity changes of Figure 1 to light passing close to the aperture edge in overfilled conditions.

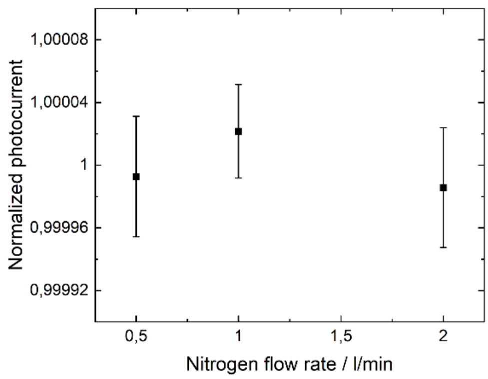

Figure 2. Normalized responsivity of the trap detector with 10-mm diameter aperture measured with 488-nm laser beam of 1.6-mm diameter at different nitrogen flow rates.

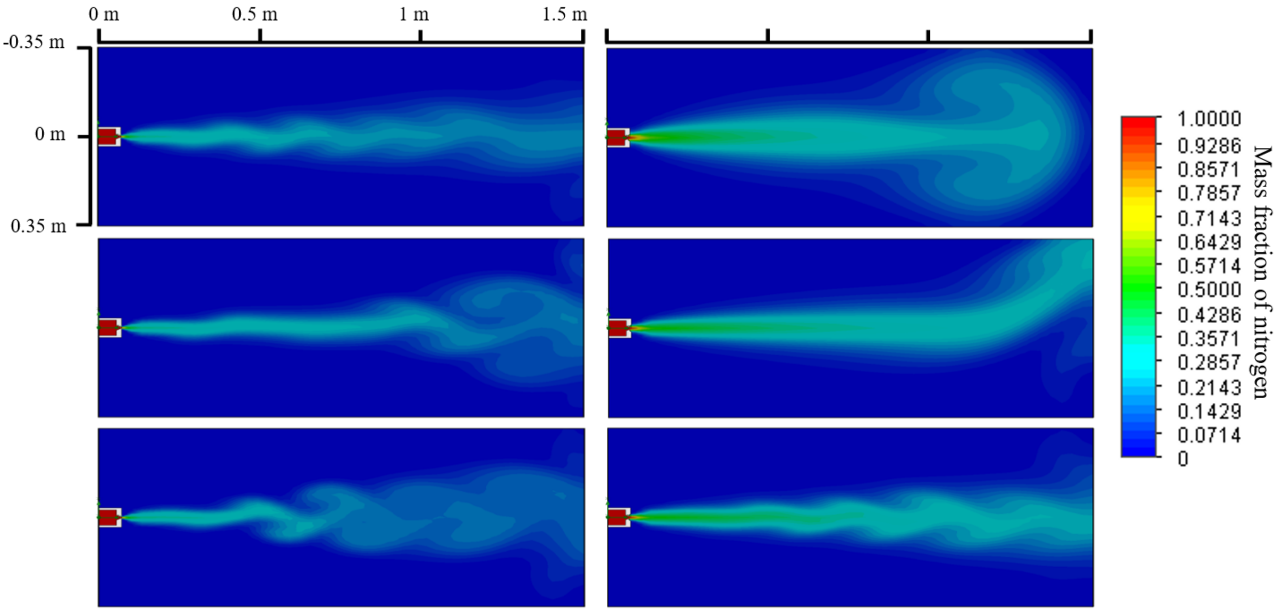

Figure 3. Simulated nitrogen flow distributions of a detector with 4 mm (left) and 10 mm (right) aperture openings with flow rates of 0.5 (top), 1.0 (middle), and 1.5 l/min (bottom). The length and the width of the simulated area are 1.5m and 0.7 m, respectively. The simulated result is shown at the steady state of the system.

SIMULATION OF NITROGEN FLOW

To further analyse the reason for the response increase, the distributions of the nitrogen fraction, pressure, and the relative humidity were simulated with Solidworks. Detector housings with aperture diameters of 4 mm and 10 mm were modelled. A turbulent flow was assumed as the inlet flow.

Figure 3 shows the simulation results at the steady state for flow rates of 0.5, 1.0 and 1.5 l/min with both aperture diameters. The pressure difference between the inside of the detector and the ambient is 0.2 Pa when using the 4-mm diameter aperture and 1.5 l/min flow rate. The turbulence makes the flow distribution change over time with higher flow rates, and the nitrogen profile in front of the detector is unstable. This is also seen in the LED measurements in Figure 1 as increased standard deviation of the photocurrent.

The nitrogen flow appears to produce a tube-like structure in front of the aperture. The refractive index of nitrogen is about 5 ppm larger than that of air [3] and thus nitrogen appears to form a gradient-index type gas lens in front of the detector. Paraxial light paths passing close to the aperture edge are expected to slightly bend towards the optical axis. As a result, the area of the detector aperture may effectively increase for a large-area LED source because of the lensing effect. For a laser source in underfilled mode, the lensing effect is expected to be much smaller, in agreement with Figure 2.

DISCUSSION

Based on our measurements, the nitrogen flow affects the response of trap detectors in overfill conditions. The gradual radial change of the nitrogen fraction, and thus the refractive index, may act as a gradient-index lens and effectively increase the aperture area of the detector.

Simulations were made for two different aperture diameters and different nitrogen flow rates to evaluate the nitrogen profile in front of the detector and its turbulence. The standard deviations of the overfill measurements support the hypothesis of the flow affecting the results. Having a small enough flow rate minimizes the effect on the measurements. At the same time, the flow rate should be kept large enough to prevent moisture and dust entering the detector.

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