Development of a photothermal interferometer for aerosol absorption measurements

S. Sjogren, E. Weingartner and H. Burtscher

University of Applied Sciences Northwestern Switzerland, CH-5210 Windisch, Switzerland
Keywords: interferometry, absorption, aerosol, soot, nitrogen dioxide (NO_2).
Presenting author email: staffan.sjoegren@fhnw.ch

Background

The aerosol absorption in the atmosphere influences our climate. Background air often has an absorption coefficient lower than 1 Mm^{-1}. Current commercial instrumentation uses predominantly filter substrates for collecting aerosol during measurements (e.g. Aethalometer, PSAP), which require corrections. We aim to develop a robust field-deployable instrument using photothermal interferometry (PTI), which measures aerosol absorption in situ, in air, directly (Moosmüller *et al.,* 2009). Our PTI prototype consists of a folded Michelson interferometer (Sedlacek, 2006).

Experimental method

The aerosol absorption is measured due to the heating of the particles as they are exposed to pulses of light with a certain wavelength (currently green light at 532 nm, diode laser, cw 0.5 W, duty cycle 50%). The heat is transferred to the surrounding air, changing its refractive index. This change is measured with an interferometer (HeNe laser, 5 mW), i.e. the phase shift between a reference arm and the arm with the aerosol and pulsed light in a measurement chamber.

The resolution (determined by the noise) of the interferometer is about $\Delta\Phi$ = 1 μrad (at 1-minute time resolution). The relation between phase shift and the absorption coefficient α is described by (Sedlacek, 2006):

$$\Delta\phi = \frac{2\pi l}{\lambda}\frac{(n-1)}{T_o}\frac{\alpha P_{\mathrm{exc}}}{4\pi a^2 \rho C_p f} \quad , \qquad (1)$$

where l is the interaction length, f is the pulse frequency and P_{exc} the power of the green light (within the boundary of the interferometer laser), respectively; n is the refractive index of air (1.000292); λ is the interferometer wavelength (HeNe, 632.8 nm); T_o is the absolute temperature; a is the radius of the interferometer beam; ρ is the density of air (1.205 kg m^{-3}); and C_p is the specific heat of air (1005.4 J kg^{-1} K^{-1}). The theoretical limit of the resolution is about 10^{-8} rad, based on the detector shot noise only (Sedlacek, 2006). There is a trade-off in the effort to approach that limit: one can also increase the signal with longer l or larger P_{exc} or with smaller a or f, for example.

Results and discussions

The prototype was tested with NO_2 (1 ppm, 3% accuracy, in synthetic air 5.0, Messer gases, Switzerland) and a typical result is shown in Figure 1. NO_2 has a well-known molecular absorption cross section of $1.42 \cdot 10^{-19}$ cm^2 $molecule^{-1}$ which corresponds to α = 345 Mm^{-1} at 25°C, 1000 mbar and 1 ppm). Soot from a Palas soot generator (model GFG 1000) was similarly detected. Further the prototype was tested with ammonium sulphate (scattering only) and no signal was detected, confirming that non-absorbing aerosol do not generate a signal in PTI instruments. Our current prototype has a detection limit of about 35 Mm^{-1}.

Outlook

Work is currently underway to develop a new prototype which is less prone to external vibrations using shock-absorbing materials. The sensitivity will be further improved by using other pump light sources. We also want to improve the long-term stability and usability of this instrument.

Conclusions

A photothermal interferometer has been tested. Advantages of the setup are its stability (quadrature point and easy interferometer adjustment during setup) and that the instrument is based on OEM components, readily available.

The interferometer absorption measurement allows comparison and validation with aethalometer-type instruments. This results in a better accuracy of aerosol absorption measurements.

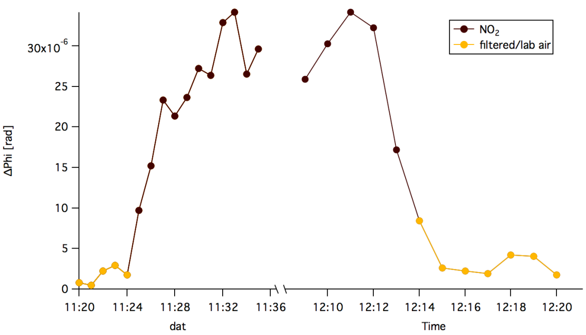

Figure 1. Typical measurement of 1 ppm NO_2 with the PTI prototype.

Moosmüller, H., Chakrabarty, R. K., and Arnott, W. P. (2009) *J. Quant. Spectrosc. Radiat. Transfer.*, ***110*** **(11)**, 844-878.

Sedlacek, A.J. (2006) *Rev. Sci. Instrum.* **77**, 064903.