Invisible-Light Labs

from proteins to stars

Invisible-Light Labs GmbH
Taubstummengasse 11
1040 Vienna, Austria

info@invisible-light-labs.com
www.invisible-light-labs.com

CHARACTERIZATION OF SUB-MICROMETER URBAN AEROSOLS WITH EMILIE™

Invisible-Light Labs GmbH

May 22nd, 2025

While ultrafine aerosol particles (UFPs) typically have significant number concentrations, their total mass is generally very low, which makes their chemical characterization extremely challenging. UFPs are the least understood components of air quality, particularly regarding their related health risks and climate impacts, due to the difficulty in capturing and characterizing such small particles. [1] We propose a new photothermal spectroscopy technique, nanoelectromechanical Fourier-transform infrared spectroscopy (NEMS–FTIR), with EMILIE™ for the rapid bulk chemical characterization of ultrafine aerosols with sizes down to 10 nm. By significantly enhancing the sensitivity of traditional FTIRs and reducing sampling times for UFPs, EMILIE™ opens the way to breakthroughs in UFP monitoring and chemical composition characterization.

SAMPLE COLLECTION OF AEROSOLS ON EMILIE™ CHIPS

A significant advantage of EMILIE™ resides in the fact that the EMILIE™ sampling and sensing chip, or EMILIE™ chip, is used both for sample collection and characterization, eliminating the need for sample transfer and therefore minimizing the risk of sample losses and contamination. Additionally, in contrast to Teflon filters, which can be used as substrates for transmission-FTIR analysis of aerosols, the EMILIE™ chips are highly transparent, with a single peak from the chip's silicon nitride (SiN) material at 835 cm^{-1}, increasing the amount of spectral information available. The sample collection and measurement concept are illustrated schematically in Figure 1, and the efficiency of the sample collection is plotted in Figure 2.

URBAN AEROSOL ANALYSIS WITH EMILIE™

To demonstrate the EMILIE™ technology for the analysis of urban aerosols down to ultrafine particles, samples were collected in an urban environment (central Vienna) for analysis via NEMS-FTIR. For pre-selection and comparison of different size fractions, urban air was collected using the Aerosol Impactor Adapter together with a Mini MOUDI™ (TSI Inc, USA) as shown in Figure 3.

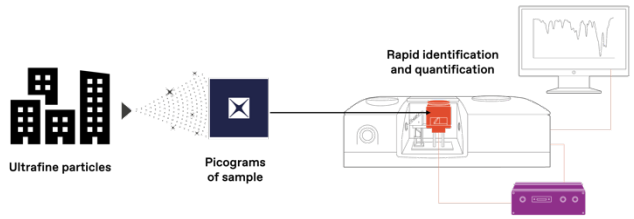


Figure 1. Aerosol samples are deposited directly on the surface of the EMILIE™ nanomechanical sampling and sensing chip prior to analysis by NEMS-FTIR.

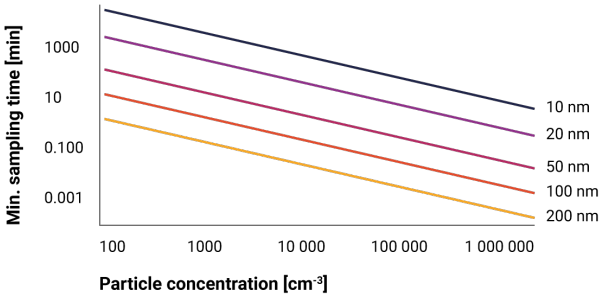


Figure 2. Estimated minimal sampling time for different particle sizes for a flow rate of 1 L/min



Figure 3. Two EMILIE™ chips placed in the Aerosol Impactor Adaptor (left) for sampling with the mini MOUDI™ (TSI Inc, USA) (right).

Invisible-Light Labs GmbH
Taubstummengasse 11
1040 Vienna, Austria

info@invisible-light-labs.com
www.invisible-light-labs.com

Sample collection was performed for 20 min for the chips placed after stage 3 and 30 min for those placed after stage 6, representing a cut-off size of 3.2 µm and 0.56 µm, respectively.

Two EMILIE™ chips were sampled in parallel using a total flow rate of 2 L/min. For subtraction of the background, a duplet of EMILIE™ chips was sampled after stage 3 of the Mini MOUDI™ with a HEPA inline filter attached to the air inlet. Figure 4 shows SEM images of EMILIE™ chips after collection of urban air after stage 3 & 6. The sample collection was performed at two different times of the day for both stages: once during rush hour and once during midday. The average particle concentrations measured during the sampling periods were approximately 6500 particles/cm^3 at midday and 13,200 particles/cm^3 during rush hour, with corresponding average particle diameters of 53 nm and 46 nm, respectively.

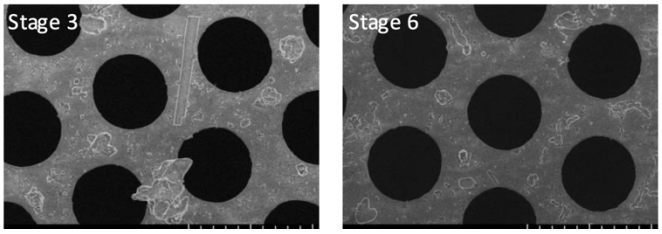


Figure 4. SEM images showing differences in the size of urban particles collected when the EMILIE™ chip is placed after stage 3 (left) and after stage 6 (right) of the Mini MOUDI™ impactor.

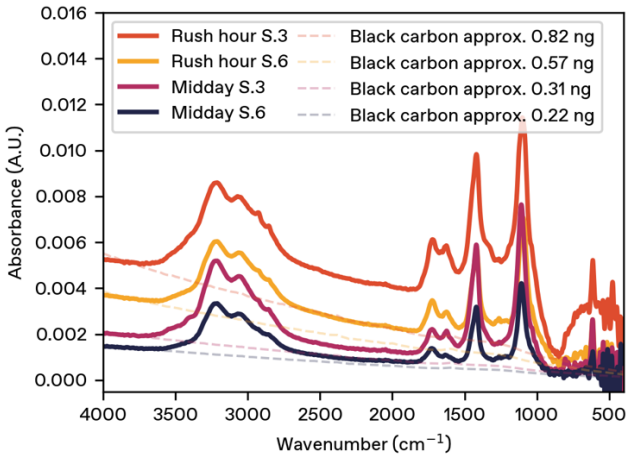


Figure 5. NEMS-FTIR spectrum of aerosols collected in an urban environment during midday and rush hour. Dashed lines indicate an elevated background due to black carbon.

The comparison in Figure 4 shows the effectively reduced size of sampled particles due to the finer cut-off in stage 6. After sampling, the resonator chips were transferred directly to the EMILIE™ nanomechanical analyzer for NEMS-FTIR analysis without any further sample processing. The SiN peak from the chip material at 835 cm^{-1} was used as an internal standard in all measurements. Urban air samples were background corrected using the prefiltered air spectra.

The processed spectra of urban aerosol shown in Figure 5 feature several peaks that can be attributed to organic and inorganic-based aerosols, in particular SO_4^{2-} (1101 cm^{-1}), NH_4^+ (1417 and 3190 cm^{-1}), NH_2 (1600 cm^{-1}), carbonyl (1712 cm^{-1}), aliphatic CH (2900 cm^{-1}), and aromatic CH (3040 cm^{-1}) [2,3]. The intensity of the rush hour spectrum is higher than during midday, in agreement with the average particle counts recorded. Further, the black carbon contribution to the NEMS-FTIR signal can be estimated by fitting a library spectrum of diesel soot to the spectra [4]. A comparison of the estimated black carbon content presents a good match to the increased trend during the rush hour. This demonstrates the large potential of EMILIE™ for the chemical characterization of aerosols and ultrafine particles.

BENEFITS OF USING EMILIE™

- Rapid collection of aerosols (10 nm – ca. 3200 nm) directly on the surface of the EMILIE™ chip.
- Rapid NEMS-FTIR characterization of aerosols.
- No sample transfer from a filter for further analysis.
- No time-consuming scanning.

REFERENCES

[1] Kumar, P. et al. "Ultrafine particles in cities." *Environment International* 66 (2014) : 1–10.

[2] Takahama, S., Ruggeri, G., & Dillner, A. M. (2016). Analysis of functional groups in atmospheric aerosols by infrared spectroscopy: sparse methods for statistical selection of relevant absorption bands. *Atmospheric Measurement Techniques*, 9(7), 3429–3454.

[3] Bondy, A. L., Kirpes, R. M., Merzel, R. L., Pratt, K. A., Banaszak Holl, M. M., & Ault, A. P. (2017). Atomic Force Microscopy-Infrared Spectroscopy of Individual Atmospheric Aerosol Particles: Subdiffraction Limit Vibrational Spectroscopy and Morphological Analysis. *Analytical Chemistry*, 89(17),8594–8598

[4] Querry M. Optical constants of mineral and other materials from millimeter to the ultraviolet, Contractor Report CRDEC-CR-88009 (1987)