



## NEMS-FT-IR Applications

Analysis of aerosols, nanoplastics, proteins, and in-situ thermal desorption with EMILIE™.  
Application Note M192

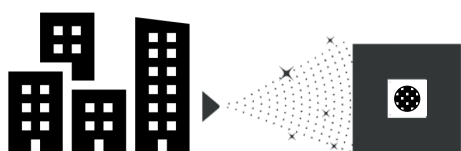
### Introduction

EMILIE™ enables highly sensitive photothermal detection with exceptional sensitivity by combining nanoelectromechanical systems (NEMS) with Fourier transform infrared (FT-IR) spectroscopy. This application note highlights four key use cases demonstrating EMILIE™'s versatility:

- Ultrafine aerosol analysis, including urban air pollutants
- Nanoplastics detection and quantification with picogram detection limits
- Dry protein characterization with clear identification of amide bands at sub-ng levels
- In-situ thermal desorption (TD) of semi-volatile compounds with simultaneous spectroscopic and mass-load monitoring.

### Application #1 – Aerosols Analysis

By combining high-efficiency capture of airborne nanoparticles as small as 10 nm with NEMS-FT-IR detection, EMILIE™ offers an ideal solution for studying airborne particulates in environmental, industrial, or occupational settings. The aerosol sample collection and measurement concept is illustrated schematically in Figure 1. An estimate of the required sample collection times for various airborne nanoparticle sizes is shown in Figure 2. For 10 nm-sized nanoparticles, sampling times can vary from minutes to a day, depending on concentration.

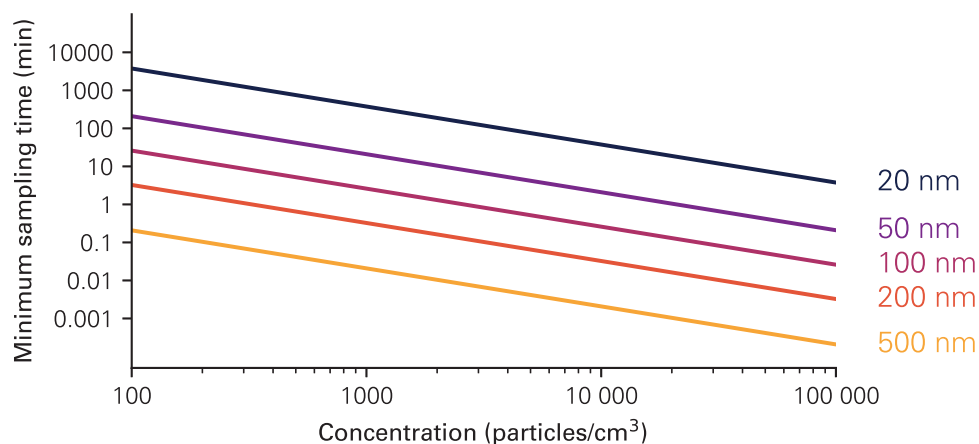


**Fig. 1**

Aerosol samples are deposited directly on the surface of the EMILIE™ chip. No further sample preparation is required before analysis by NEMS-FT-IR.

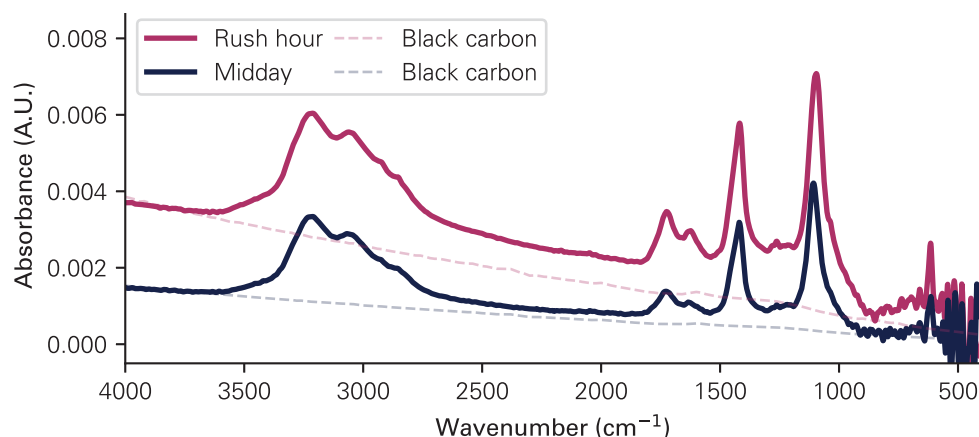
1. Aerosol particles collected on EMILIE™ chip

2. NEMS-FT-IR characterization with EMILIE™



**Fig. 2**  
Estimated sampling times for different airborne particle sizes at a flow rate of 1 L/min.

In one demonstration, EMILIE™ chips were used in a multi-stage impactor to collect urban aerosols with a size below 0.56  $\mu\text{m}$ . Within a 30-minute sample collection period at a flow rate of 2 L/min, the aerosol chemical signatures of organic and inorganic-based aerosols could be observed as shown in Figure 3. Peaks for  $\text{SO}_4^{2-}$  (1101  $\text{cm}^{-1}$ ),  $\text{NH}_4^+$  (1417  $\text{cm}^{-1}$  and 3190  $\text{cm}^{-1}$ ),  $\text{NH}_2$  (1600  $\text{cm}^{-1}$ ), carbonyl (1712  $\text{cm}^{-1}$ ), aliphatic CH (2900  $\text{cm}^{-1}$ ), and aromatic CH (3040  $\text{cm}^{-1}$ )<sup>[1, 2]</sup> were clearly resolved. The black carbon content could be estimated using a diesel soot reference<sup>[3]</sup>.



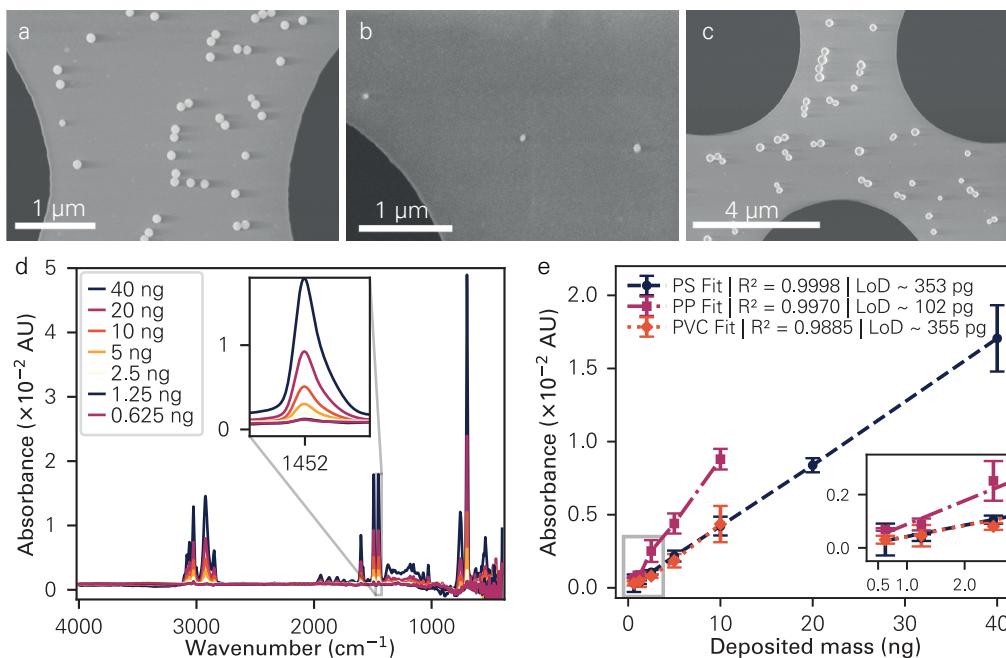
**Fig. 3**  
FT-IR spectrum of ultrafine aerosols collected in an urban environment at midday and rush hour, showing the distinct chemical fingerprint of urban aerosols as well as the presence of black carbon.

## Application #2 – Nanoplastics Detection and Polymer Characterization

Detecting and identifying nanoplastics is a growing analytical challenge. EMILIE™ helps bridge this technological gap by enabling qualitative and quantitative analysis of nanoplastics down to the picogram range. As shown in Figure 4, EMILIE™ coupled to a VERTEX 70 could be used to detect polystyrene (PS,  $\text{Ø}100\text{ nm}$ ), polypropylene (PP,  $\text{Ø}54\text{ nm}$ ), and polyvinyl chloride (PVC,  $\text{Ø}262\text{ nm}$ ) nanoparticles with limits of detection (LoD) of 353 pg, 102 pg, and 355 pg, respectively<sup>[4]</sup>. This capability opens the door to advanced studies of nanoplastics in both environmental and industrial settings.

**Fig. 4**

a) - c) SEM images of PS, PP, and PVC nanoparticles, respectively, deposited on an EMILIE™ chip. d) NEMS-FT-IR spectra of varying mass loads of PS nanoparticles. e) Calibration curves for the 1452 cm<sup>-1</sup> PS peak, 1377 cm<sup>-1</sup> PP peak, and 1427 cm<sup>-1</sup> PVC peak (error bars N=3, 95% C.L.).



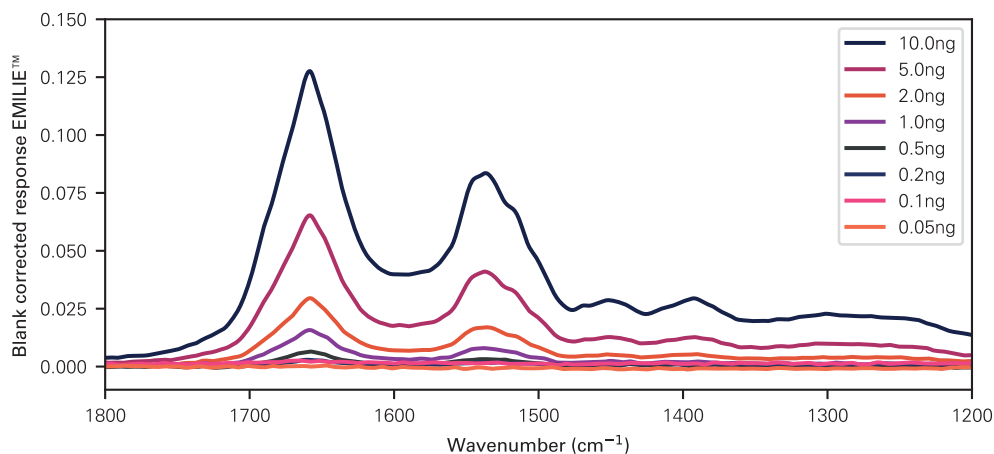
### Application #3 – Dry Protein and Biomolecule Analysis with Picogram Sensitivity

FT-IR spectroscopy is routinely used for the quantification and characterization of proteins and other biological materials. However, low sensitivity combined with the overlap between a protein's amide I band (1700-1600 cm<sup>-1</sup>) and water's HOH-bend (1643 cm<sup>-1</sup>) can make the analysis of very small amounts of proteins challenging with conventional FT-IR instrumentation. EMILIE™ overcomes these limitations by enabling highly sensitive analysis under vacuum conditions.

As a demonstration, 50 pg to 10 ng of protein bovine serum albumin (BSA) were dropcasted (20 nL) on EMILIE™ chips. Figure 5 shows BSA's amide I (1665 cm<sup>-1</sup>), amide II (1536 cm<sup>-1</sup>), and amide III (1400 cm<sup>-1</sup>) bands with high spectral clarity for sub-nanogram samples and with a LoD evaluated at 200 pg. These results are comparable to the LoD achieved for microarray imaging of BSA using a liquid nitrogen-cooled mercury-cadmium-telluride detector<sup>[6]</sup>, demonstrating that NEMS-FT-IR is a suitable room-temperature alternative for biochemical samples. This method is ideally suited for limited-volume biological samples, pharmaceutical development, nanomedicines, and other applications where sample quantities are limited and high-sensitivity is essential.

**Fig. 5**

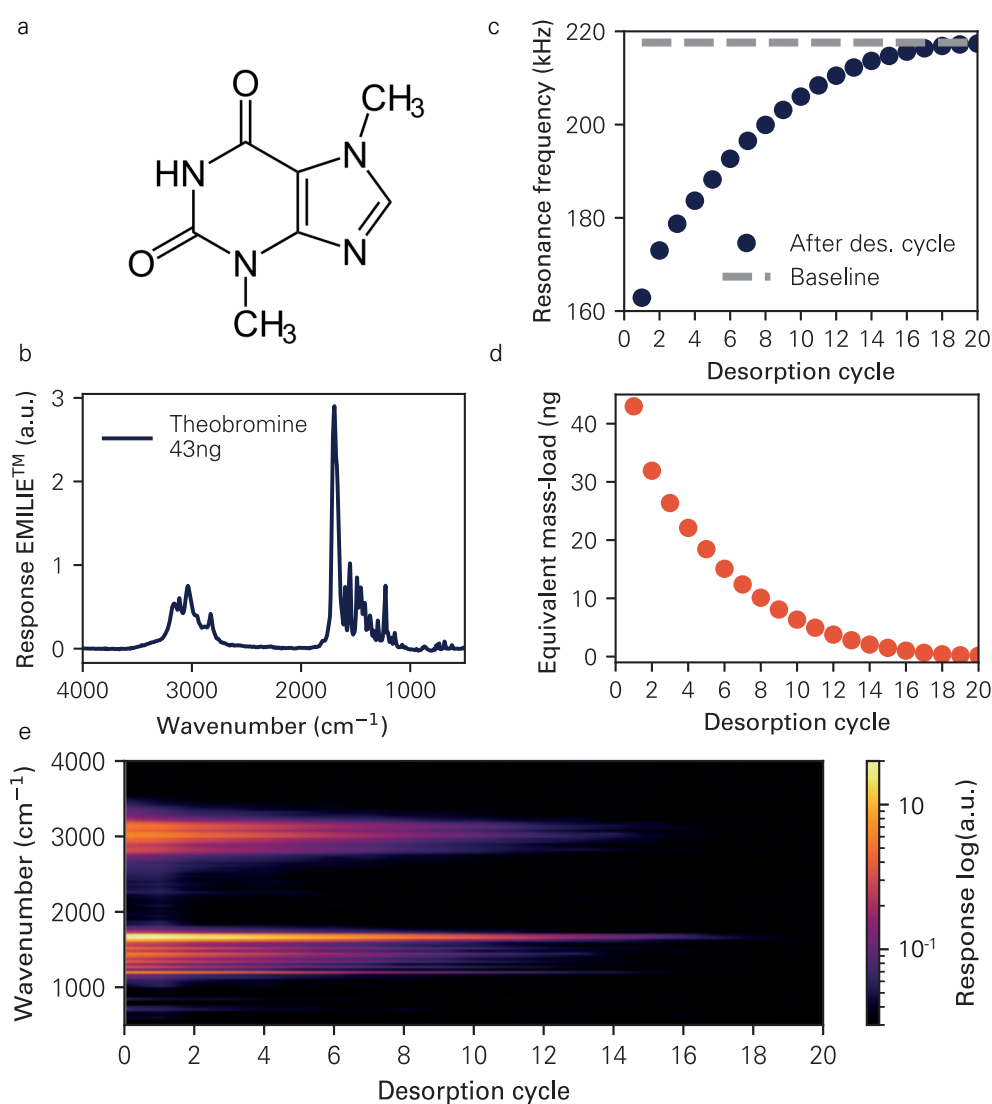
Average (N=3) NEMS-FT-IR spectra for various amounts of BSA deposited on the EMILIE™ chip.



## Application #4 – In-Situ Temperature Desorption

EMILIE™ uniquely integrates NEMS-FT-IR spectroscopy with temperature control, enabling in-situ thermal desorption (TD) studies at the microscale<sup>[6]</sup>. Unlike standard thermogravimetric methods, NEMS-FT-IR-TD with EMILIE™ allows monitoring of the analyte placed on the EMILIE™ chip as it is heated under vacuum. This technique allows for thermal desorption of semi-volatile compounds and even separation of mixtures of analytes as well as thermal stability studies. In a demonstration with theobromine (Figure 6a,b), a semi-volatile compound, EMILIE™ tracked frequency changes (Figure 6b), mass loss (Figure 6c), and spectral changes (Figure 6d), across repeated 80°C heating cycles.

NEMS-FT-IR-TD with EMILIE™ is an attractive new tool for analyzing semi-volatile compound mixtures, stability testing of pharmaceuticals, or desorption behavior of various analytes available in limited quantities.



**Fig. 6**

a) Theobromine.  
b) NEMS-FT-IR spectrum of 43 ng theobromine recorded with EMILIE™ and a VERTEX 70.  
c) The resonance frequency of the EMILIE™ chip is recorded after each desorption cycle. The resonance frequency increases until all the theobromine has been desorbed and a frequency plateau is reached.  
d) The equivalent mass-load of theobromine can be evaluated from the EMILIE™ chip's resonance frequency. The theobromine mass present on the surface of the chip decreases with each desorption cycle until all the theobromine has been desorbed.  
e) A heat map displays the spectral changes observed in theobromine's NEMS-FT-IR spectrum after each desorption cycle, until all theobromine has been desorbed from the sensing surface.

### Key advantages of Using EMILIE™

- Efficient capture of aerosols (10 nm – 3.2 µm) directly on the EMILIE™ chip.
- No sample transfer from a filter (ideal for aerosols and nanoplastics).
- Integrated thermal control for in-situ temperature desorption and thermal stability studies.
- High sensitivity enables sub-ng analyses without the need for cryogenic cooling.

### References

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- <sup>[2]</sup> Bondy, A. L., Kirpes, R. M., Merzel, R. L., Pratt, K. A., Banaszak Holl, M. M., & Ault, A. P. Atomic Force Microscopy-Infrared Spectroscopy of Individual Atmospheric Aerosol Particles: Subdiffraction Limit Vibrational Spectroscopy and Morphological Analysis. *Analytical Chemistry*, 89(17), 8594–8598 (2017).
- <sup>[3]</sup> Querry, M. Optical constants of mineral and other materials from millimeter to the ultraviolet, Contractor Report CRDEC-CR-88009 (1987)
- <sup>[4]</sup> Popovic, J.T., Hiesberger, J., Šesto, Luhmann, N., E., Giesriegl, A., Lafleur, J.P., and Schmid, S., Nanoplastic Analysis with Nanoelectromechanical System Fourier Transform Infrared Spectroscopy, arXiv:2504.10192 (2025).
- <sup>[5]</sup> Lux, L., Phal, Y., Hsieh, P.-H. and Bhargava, R. On the limit of detection in infrared spectroscopic imaging. *Applied Spectroscopy*, 76(1), 105-117, (2002)
- <sup>[6]</sup> Luhmann, N., West, R. G., Lafleur, J. P. & Schmid, S. Nanoelectromechanical infrared spectroscopy with in situ separation by thermal desorption: NEMS-IR-TD. *ACS Sensors* 8, 1462–1470 (2023).

