

Dual-Channel Fluorescence Optical Sensor for Microplastic Detection and Polymer Classification

Yuliu Li¹, Valerio Allegra¹, Eleonora Nicolai², Roberto Pizzoferrato³, Corrado Di Natale¹, Alexandro Catini¹

¹ Department of Electronic Engineering, University of Rome Tor Vergata, Via del Politecnico 1, 00133 Rome, Italy,

² Departmental Faculty of Medicine, UniCamillus-Saint Camillus International University of Health Sciences, Via di Sant'Alessandro 8, Rome, Italy,

³ Department of Industrial Engineering, University of Rome Tor Vergata, Via del Politecnico 1, 00133 Rome, Italy
catini@ing.uniroma2.it

Summary:

Microplastic pollution in aquatic systems poses ecological and health risks. However, current detection methods (e.g., FTIR, Raman spectroscopy) are time-consuming, costly, require skilled personnel and lack field applicability. We present a dual-channel fluorescence-based optical sensor for rapid detection and classification of microplastics dispersed in water. The detection is accomplished by exploiting the affinity of fluorescent solvatochromic dye DANS with plastic microparticles. A dual-channel pulse intensity spectral analysis of fluorescence emission enables the identification of at least three different microplastics: polypropylene (PP), polystyrene (PS) and polyethylene terephthalate (PET).

Keywords: optical sensor, microplastic, fluorescence, water contaminants, environmental monitoring

Introduction

Microplastic pollution is a critical environmental and health concern, with particles detected in drinking water, marine ecosystems, and even human blood. Conventional detections are laboratory methods, such as Fourier-transform infrared spectroscopy and Raman microscopy, that are accurate but costly and time-consuming. Meanwhile, field-applicable alternatives like Nile Red staining suffer from low specificity and interference from organic matter [1]. To improve the performance of dyes, we developed a fluorescence sensor that combines dye-enhanced selectivity and dual-channel detection, in order to design a low-cost and portable device. The system is based on the chemical and optical properties of DANS (4-dimethylamino- 4'-nitrostilbene), where the selective binding of microplastics is signaled by a change in the fluorescence emission spectra [2]. Simultaneous dual-channel fluorescence measurement in the spectral ranges of 450–550 nm (nonpolar dominant) and >550 nm (polar dominant) enables the identification of plastics by peak intensity spectral analysis.

Methodology

The optical sensor used in this work is an upgraded version of our previous single-channel optical device [3]. The experimental setup

includes three main parts: fluorescence labeling and excitation, dual-channel optical detection, and signal processing. Three microplastics with different polarities were used: nonpolar PP (25–45 μm fragments), PS (30 μm beads) with moderate polarity and polar PET (1–49 μm fragments). The fluorescence labeling was performed with 1 mg/mL DANS dye stock solution prepared in acetone to achieve a concentration of 1 mg/L in prefiltered water with 0.22 μm Nylon filters. The experimental setup is shown in Fig. 1.

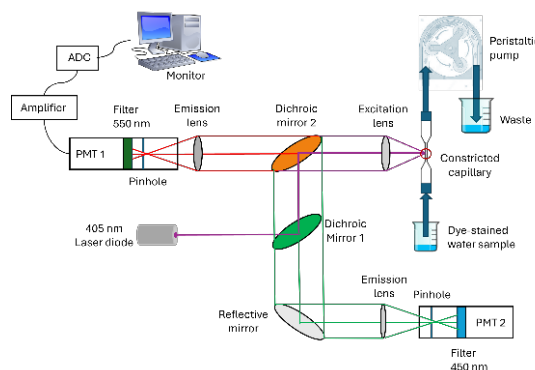


Fig. 1. Experimental setup of the Dual-channel optical sensor for microplastic detection.

A 405 nm laser diode (CW output power of 4.5 mW) is used to excite the DANS-labeled microplastics in liquid samples flowing through a glass

capillary with a constriction part of 200 μm . The dual-channel detection system captures emitted light pulses at 450–550 nm and wavelengths longer than 550 nm by using two dichroic mirrors and optical filters. A MATLAB-based script has been developed to acquire the signals and perform peak detection, pulse duration analysis, and peak area calculation. For comparison, fluorescence microscopy observation and spectroscopy measurements were also performed to characterize the fluorescence properties of the DANS-labeled microplastics.

Results

The fluorescent and solvatochromic dye DANS exhibits a strong binding to PET via sulfonamide-polar interactions and hydrophobic affinity for PP. Both the fluorescence spectra (see Fig. 2) and the microscopy images (see Fig. 3) show the shift towards longer wavelengths of the more polar polymer PS and PET, while PP emits fluorescence mainly in the green/blue region.

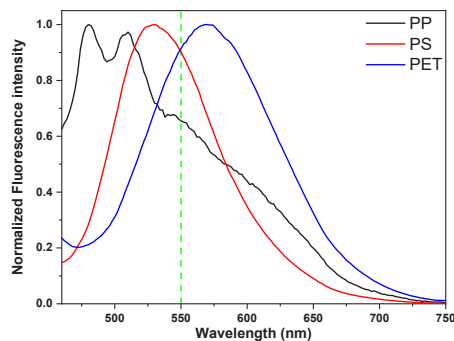


Fig. 2. Normalized fluorescence spectra of DANS-labeled plastics under 405 nm excitation. The green dashed line at 550 nm is the separation wavelength of the two channels.

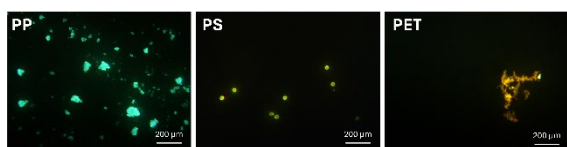


Fig. 3 Fluorescence microscopy of DANS-labeled PP, PS and PET under excitation of 405 nm laser and with 450 nm optical filter.

The system employs 405 nm excitation and two synchronized detection channels, Channel 1 ($\lambda > 550$ nm) for yellow/red emission (indicative of polar polymers) and Channel 2 ($\lambda > 450$ and < 550 nm) for blue/green emission (dominant for non-polar polymers). By analyzing the intensity of each fluorescence pulse (area under peak) and its ratio (P_1/P_2) between channels, we achieved the identification of the polymers, while particle counting is performed via thresholding the combined fluorescence signal. As shown in Fig. 4, the angular direction calculated as the ratio of the peak area of the two channels are specific

for each microplastic, enables the identification of the plastics (see Tab. 1). The peak area ratio decreases from 18.98 to 1.15 as microplastic polarity increases, with polymers fluorescing more strongly in the yellow/red region. This suggests a method to predict system behavior for other polymers.

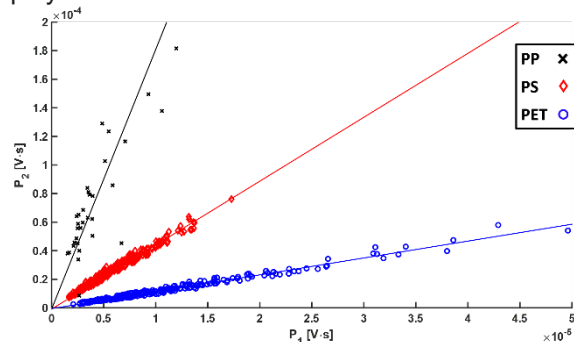


Fig. 4. Intensity of fluorescence pulses of the two spectral channels for three DANS-labeled polymers.

Tab. 1: Fluorescence peak, dielectric constant and channel intensity ratio of the three microplastics.

Microplastic	Fluorescence peak (Exc. 405 nm)	Peak area ratio (P_1/P_2)
PP	480 nm	18.98 \pm 5.41
PS	530 nm	4.51 \pm 0.31
PET	568 nm	1.15 \pm 0.11

In conclusion, the dual-channel system provides information on the interaction of DANS with microplastic, providing not only the evaluation of the particle density but also the polymer identification. This low-cost, field-portable system offers a practical solution for environmental microplastic monitoring.

References

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