

Remote sensor systems for the automated identification of plastics

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In many production processes it is necessary to identify plastics prior to sorting, purification or forming steps. Another large field is recycling, where, due to the relatively low value of the material handled, high throughputs at low costs are of essence. The article contains principle considerations about how to make a remote identifier fast and economic. Examples are elaborated on different material streams.

Keywords: Plastics, identification, remote, spectroscopy, infrared, high throughput.

Introduction

Plastics have become an indispensable element of daily life already more than forty years ago, but only recently it was publicly recognized, that recycling of these materials is useful and necessary. Due to mutual blending incompatibilities the diverse Plastic varieties need to be recycled as purely as possible; a real challenge for optical recognition technology, especially because high throughputs at low costs are of the essence due to the relatively low value of the material handled. This statement is true for all four major streams of plastics appearing at the dump sites: Packaging waste, textiles (mainly as carpets), electronic goods and automobiles.

Basics

High material throughput of a sorting system requires a fast and—necessary to ensure a fast flow of material—remotely operating recognition system. Having to fulfill both requirements simultaneously leads to the systems bottleneck as depicted in Figure 1.

Optical sensitivity

The sensitivity of any optical system is mainly limited by its detectors noise and by the amount of light that reaches this detector after having inter-

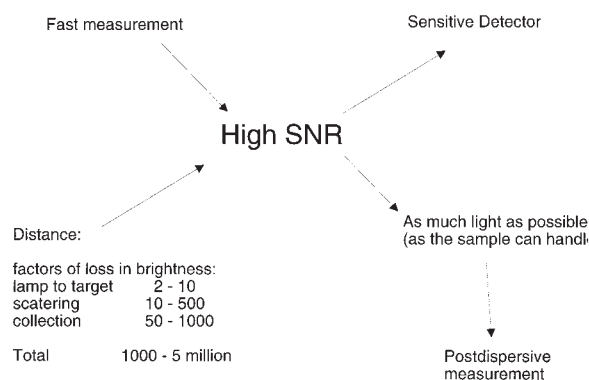


Figure 1. Linkage of necessities for high throughput recognition.

Table 1. Detectors recommendable for sorting.

Material	Cut off (nm)	Sensitivity (D^*)	Average Price (\$) ²
Silicon	1050	$\sim 10^{15} - 10^{17}$	1–5
InGaAs (standard)	1650	$\sim 10^{13} - 10^{14}$	20–50
InGaAs (extended)	1900	$\sim 10^{12} - 10^{13}$	100–300 ³
InGaAs (extended)	2500	$\sim 10^{11} - 10^{12}$	500 ³
InAs	3000	$\sim 10^{11} - 10^{12}$	500 ³
PbS ¹	3500	$\sim 10^{11}$	—
MCT	5000	$\sim 10^{10} - 10^{11}$	500 ³

¹speed limitations may appear for some applications.

²for a single element detector with an active area of 1 mm².

³add another \$500–1000 for thermoelectric cooling.

acted with the target as completely as possible. Since most plastics are opaque, measuring remotely can only be done in diffuse reflectance, where large light losses occur. This can be partially offset by using a post-dispersive system, where the amount of light reaching the sample is only limited by the thermal stability of the sample itself and not by the extend of the dispersing or modulating system.

Detector sensitivity is mainly limited by material, cutoff wavelength and temperature of operation. For high speed operation only semiconductor detectors are suited and for those the relation holds: ‘The longer the cutoff wavelength, the smaller the bandgap, the higher the dark current and it’s noise’. Never use a detector with a longer cutoff wavelength than your application really requires!

Since for industrial applications the use of liquid nitrogen or cryogenic coolers is prohibitively expensive, the selection of possible detectors is already limited to uncooled or thermoelectrically cooled types. Table 1 shows a list of recommendable detectors for sorting:

In order to use all that technical information we first need to know at which wavelength range we

want to measure, leading us to the question: Where is the information?

We can find the answer by looking at the spectra of the simplest possible Polymer, Poly Ethelene (PE) which are shown in Figure 2. In these spectra five distinct regions can be identified, differing in transition strength as well as in richness of structure:

- (a) the fingerprint region below 2000 cm⁻¹
- (b) the C–H stretching ground vibration around 3000 cm⁻¹
- (c) combination bands of (a) and b), as well as the first overtone of b) lying between 1700 and 2500 nm
- (d) combination bands of (a) and the first overtone of (b), as well as the second overtone of (b) lying between 1150 and 1650 nm
- (e) combination bands of a) and the second overtone of (b), as well as the third overtone of (b) lying between 850 and 1150 nm.

In (a) and (b) just one quantum state is changed, in (c) two, in (d) three and in (e) already four. The transi-

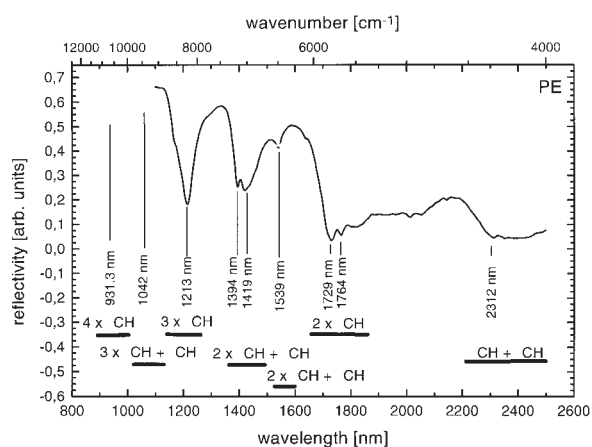


Figure 2(a). NIR spectrum of Polyethelene with the dominating bands characterised.

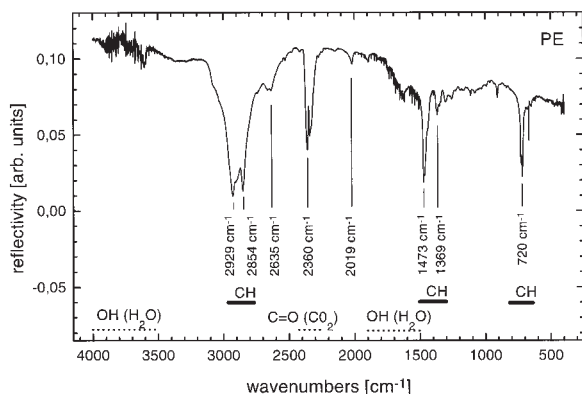


Figure 2(b). MIR spectrum of Polyethelene with the dominating bands characterised.

tion strength falls with the number of states changed and the penetration depth increases vice versa as shown in Table 2:

Each of these five regions has proven to contain enough information to enable proper sorting of polymers. Which of them to choose, depends strictly on the boundary conditions of the application as speed requirements, penetration depth wanted, cost frame, and the presence or absence of carbon based black colorants, which spoil alternatives (c) to (e). Unfortunately area (a) containing the highest concentration of specific information is ill-suited for remote measurement due to high thermal backgrounds and a lack of non-cryogenically cooled sensitive detectors.

In all other sectors our group has performed R&D projects that will be presented briefly in the following chapter.

Examples

Area (b), the groundtone of the C–H stretching vibration, is advantageous for the remote recognition of carbon black colored plastics as needed in the recycling of electronic goods or automobiles. A detailed paper of this work can be found in this book by F. Kowol *et al.* (P6 INSTRU).

In area (c), where a lot of work has been done for the recognition of packaging plastic waste¹⁻⁴, our group developed two instruments for the recycling of carpets. The main problem here was to reliably detect the minute differences between N6 and N66. A detailed study is given also in this book by B. Kip *et al.*

In area (d) our own installation for the sorting of packaging waste^{5,6} is operated as outlined by R. Feldhoff *et al.* in the Proceedings of NIR 95. This

Table 2. Transition moments α and penetration depths for the different harmonics of the C–H stretching vibration.

Harmonic #	1	2	3	4
Wavelength	~ 3.5 μm	~ 1.7–2.5 μm	~ 1.15–1.65 μm	~ 0.85–1.15 μm
α [mm^{-1}]	55–35	0.6–0.3	0.15–0.04	0.015–0.006
a [mm]	0.018–0.029	1.7–3.3	6.7–25	67–170

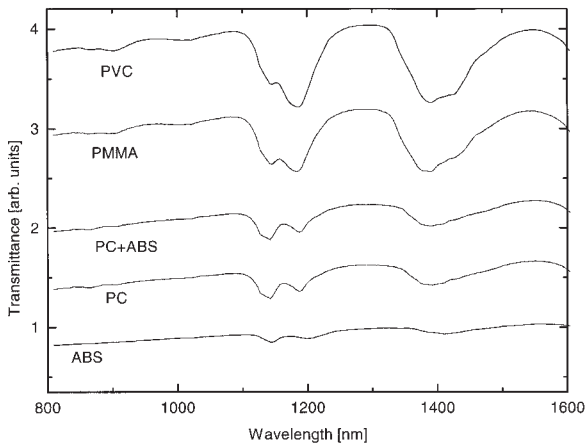


Figure 3(a). Spectra of some technical polymers in the wavelength range of standard InGaAs detectors.

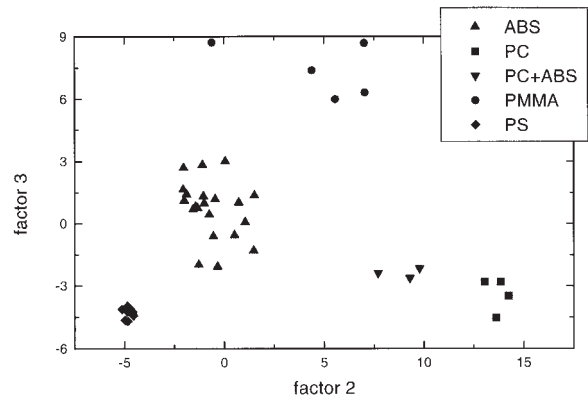


Figure 3(b). PCA plot of the spectra from some technical polymers in the wavelength range of standard InGaAs detectors.

same setup is also very suited for the recognition of non black technical plastics. The spectra of some technical plastics are shown in Figures 3(a) and 3(b) showing a clusterplot, demonstrating the principal separation power.

With another grating spectrometer equipped with an 256 element Si array, data were taken in area (e), again on used and soiled packaging waste. The spectra shown in Figure 4(a) have been averaged from spectra taken on ten different samples of the respective polymers each. The clear potential for distinc-

tion can already be seen from the spectra and are highlighted further in the PCA plot of Figure 4(b). The only drawback of the method seems to be the high measurement time of several seconds, caused by the very weak absorbtions.

Conclusions

In five different spectral regions the recognition of polymers is feasible and being practiced. Which

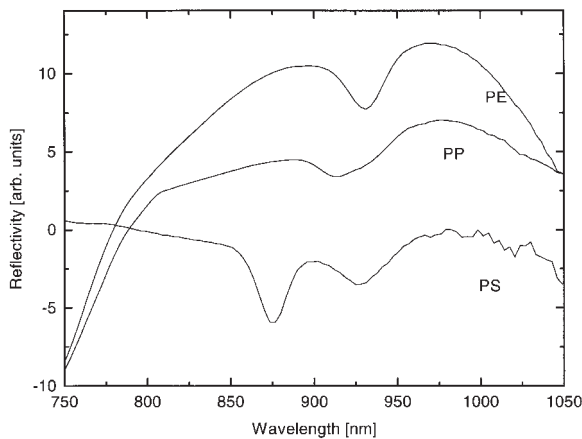


Figure 4(a) Averaged typical spectra from used packaging articles.

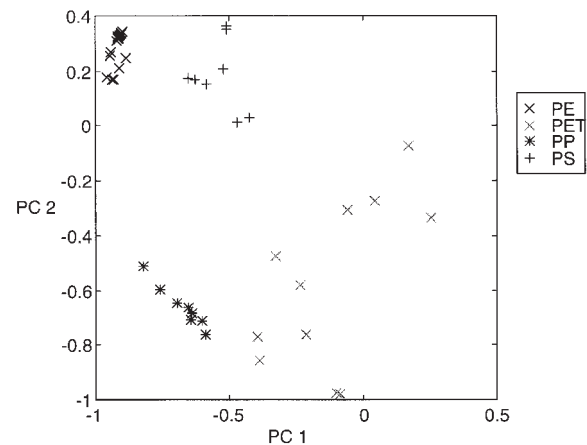


Figure 4(b). PCA plot of spectra from used packaging articles.

to choose depends strictly on factors like speed requirements, penetration depth wanted, cost frame, and the presence or absence of carbon based black colorants.

With this selection of spectroscopic tools available fast and economic recognition of plastics is no longer a dream, but became state-of-the-art during the past few years.

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