Indium Gallium Arsenide NIR Photodiode Array Spectroscopy

Part II: Plastic Waste Sorting Applications of a Multiplexed NIR Spectrometer

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George A. Gasparian *and* **Hartmut Lucht**
Greetings, dear readers. How goes the battle? If I met you at PittCon, then hello again. If I actually sprang for a drink, my guess is that you thought, like the farmer whose bull died, "Funny, he never did that before."

Seriously, I trust you enjoyed the first installment about InGaAs diode arrays, which appeared in the February Molecular Spectroscopy Workbench column (1). This month's installment shows how they can be applied. I love it when an instrument/device company approaches me and asks if I'm interested in (fill in the blank). The only thing I'm not interested in is manual labor. If any of you out there have suggestions for future columns or have ideas to share, my contact information appears at the end of the column. Enjoy!

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In Germany, about 2.6 million cars reach the end of their useful lives each year. It is forecast that this number will increase to 3 million this year (2). Therefore, a high rate of recycling will be needed as the number of end-of-life vehicles increases. We expect more than 100 million cars to be scrapped in Europe during the next 10 years.

By 1990, between 10% and 14% of the weight of a car consisted of plastic components. Plastic is used for qualities such as impact and corrosion resistance, low weight, and economic benefit. This content will rise by 2005 to about 25% of the weight, and it is likely that many new types of plastic will be used.

The most commonly used plastic types are: polyethylene, polypropylene, polystyrene, polybutylene terephthalate, acrylonitrile-butadiene-styrene, polyvinyl chloride, polyamide, polycarbonate, polyurethane, polyphenylene oxide, and poly methylmethacrylate. In contrast with household wastes, main fractions such as the polyolefins polypropylene and polyethylene or polyethylene terephthalate are not found. In addition to the pure types of plastic mentioned above, there are plastic blends and materials colored by black graphite. The identification of these materials is difficult.

The common way of recycling an old car leads from the scrap yard directly into the shredder. One quarter of the output of the shredder must be separated into the so-called shredder light component, which is a mixture of plastics, glass, pad rubber, and other materials that cannot be used for steel production. The total output of this element is useless waste. The main constituents of this light element are plastics and rubber. They could be used as high-quality raw materials if separation to a high level of purity could be achieved.

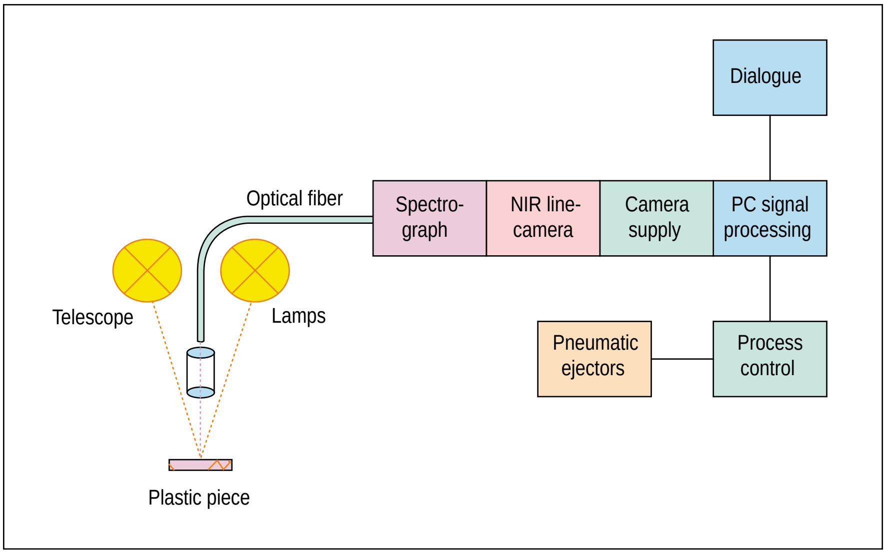

Figure 1. Schematic diagram of an NIR spectrometer.

All trends show that plastics usage will increase in the future. For this reason, further developments should be directed toward achieving a high-quality recycled product because:

- waste storage is limited
- resources are running short
- incineration is no real alternative and is rejected by the public
- incineration residuals are contaminated with toxic compounds and must be taken to special landfill sites.

Recycling waste can be a valuable contribution to securing our quality of life, health, and an intact environment.

STATE OF SCIENCE AND TECHNOLOGY: ALTERNATIVE SOLUTIONS

Plastic recycling has been confined to processing mixed and contaminated plastic objects into building materials and raw materials. Standard technologies are used to melt and remold plastic waste into low-grade products for the manufacture of building materials, which at best can be used as substitutes for wood and concrete. Recycling processes can only become economically viable if a high-quality recycled material is achieved. To achieve this, a high degree of plastics purity is required. To separate a wide range of plastics automatically, selective high-resolution sorting procedures are essential. In addition, the identification of black plastics demands the development of new, highly sensitive sensor systems.

Large plants that separate plastics at a rate of about 1000 kg/h or faster commonly use the well-known gravity separation process. Whether the float-and-sink process or the hydrocyclone centrifugal field method is used, or whether these are used together, is determined by the specific problems at hand. The materials are separated into light and heavy components. These plants cannot be used for the variety of plastics in automobile waste.

Polymers typically absorb infrared (IR) light by harmonic and combination oscillations of the molecules. In the near-infrared (NIR) range, 0.7–2.5 mm absorption bands correspond to the second harmonics or second overtones (3, 4). These oscillations are far weaker than the fundamental harmonics and their interpretation is more complex.

Advantages of spectroscopic measurement in the NIR range are:

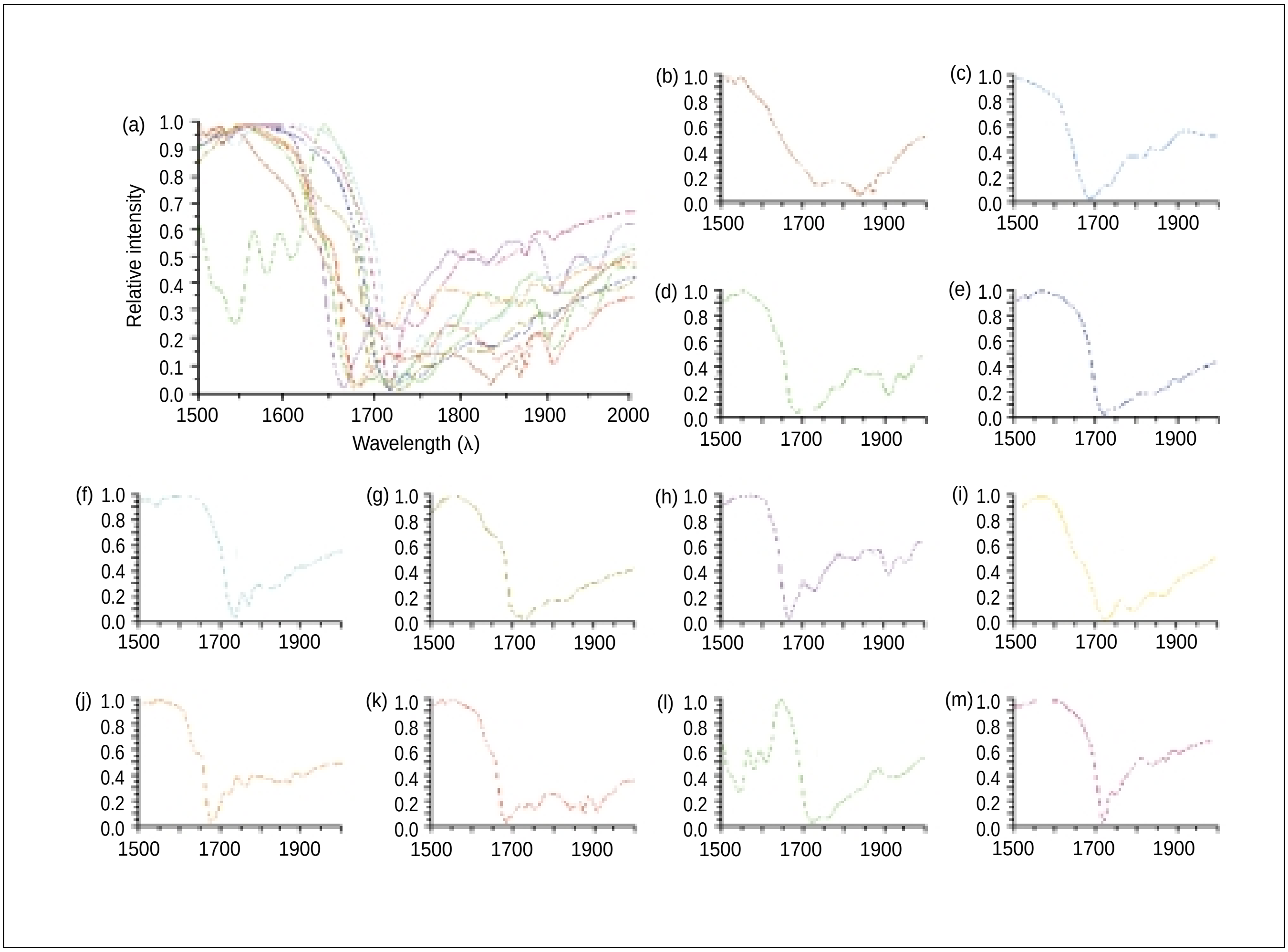

Figure 2. NIR absorption spectra of commonly used plastics. Shown are (a) combined absorption spectra and individual spectra of (b) polytetrafluoroethylene, (c) polycarbonate, (d) polymethylmethacrylate, (e) acrylic, (f) polyethylene, (g) polypropylene, (h) polyethylene terephthalate, (i) polyurethane, (j) polystyrene, (k) acrylonitrile-butadiene-styrene, (l) polyamide, and (m) polyvinyl chloride.

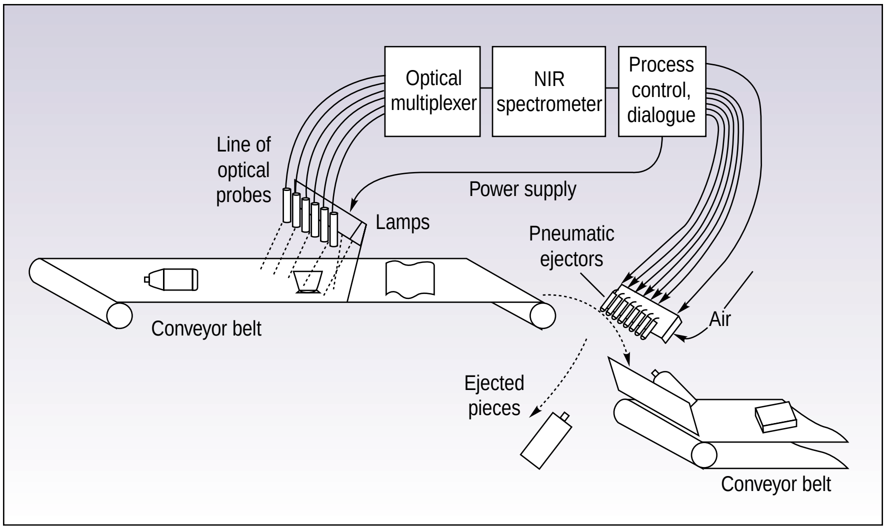

Figure 3. Automated plastic sorting using an optical multiplexer.

• high sensitivity and time resolution with readily available detectors
• well-researched beam guidance and transmission through media such as glass and quartz
• high velocity of measurement and identification
• insensitivity toward atmospheric influences and contamination.

The remainder of this article will briefly describe some specific applications of NIR spectroscopic instrumentation in the identification and separation of plastic wastes from automobiles.

INSTRUMENTATION

Figure 1 is a schematic diagram of a commercial NIR spectrometer used in plastics recycling (KUSTA 4002, LLA GmbH, Berlin-Adlershof, Germany). The system incorporates a spectrograph with a holographic concave grating and an indium-gallium-arsenide (InGaAs) photodiode array to measure the absorption bands. The measuring time for plastics identification is less than 0.5 ms. Figure 2 shows a series of spectra typical of the plastics found in car wastes.

The very high velocity of the equipment enables the use of an optical multiplexer. Many different optical probes are linked via the multiplexer to a single NIR instrument.

Figure 3 shows the use of a line of optical probes for automated plastic sorting of household waste such as plastic bottles and cups. Above a conveyor belt, a line of 16 optical probes is fixed to pick up the scattered light of the moving plastic bottles. The probes control a belt area of about 6 cm in diameter. All 16 probes sample a belt width of 1 m. The light collected by the line of probes is transferred to the spectrometer via the fiberoptical multiplexer. The line scanning rate of the probes ranges to as high as 40 Hz. Such equipment can completely control a conveyor belt to velocities as high as 2.4 m/s.

The analyzer's computer calculates more than 160,000 spectral data points for each identification. The spectrometric software identifies the plastic type, the position on the conveyor belt, and the extension of the body. With this information, a free programmable controller tracks each plastic part along the sorting conveyor and triggers a pneumatic valve to eject the preselected plastic type onto the appropriate take-away conveyor.

Figures 4–6 are photographs of this type of instrumentation in use at actual plastics recycling plants. Such a system, Unisort (operated by RTT Systemtechnik GmbH), is shown in Figure 4. It operates at a feed rate of about 1000 kg/h. Figures 5 and 6 show an instrument named criterion plus, owned by Waagner-Biro Binder, which is able to sort five or more types of household plastic waste in one step. This system uses a chain belt to convey the plastic compo-

Figure 4. The Unisort system for automated plastic sorting of household waste.

Figure 5. The feeding part of criterion plus.

nents. While passing the line of probes, the plastic type is measured in all 16 tracks. The process software controls each identified plastic piece along the way behind the probes and triggers pneumatic ejectors at the stages of predefined plastic type. The sorted plastic pieces are then taken away in big bags.

As car makers continue to expand their use of plastic materials, this technology could have significant economic and environmental benefits.

Figure 6. The ejecting stages of criterion plus.

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