Sensor technology is progressing rapidly, and offers an economical solution to hitting EU waste targets by facilitating the production of homogenous waste streams. Bob Grietens reports on the systems currently being developed across Europe.

Get it sorted

Efficiency in separation systems

Recovering high quality material from waste saves money and energy. Therefore the most advanced waste sorting systems are equipped with sensor technology in order to accurately identify different materials based on their physical properties. To gain single-variety plastics their absorption-spectrum in the short wave infrared (SWIR) range is analysed by infrared sensors.

The absorption spectrum of various plastic materials creates characteristic curvatures in the short wave infrared (SWIR) range. These can be captured and evaluated to control the homogeneous separation of plastic parts for recycling at low cost. New and innovative sensor structure has enabled the development of extremely small image capture units. As a consequence, system designers have a lot more freedom in finding the optimal layout for efficient separation and sorting systems.

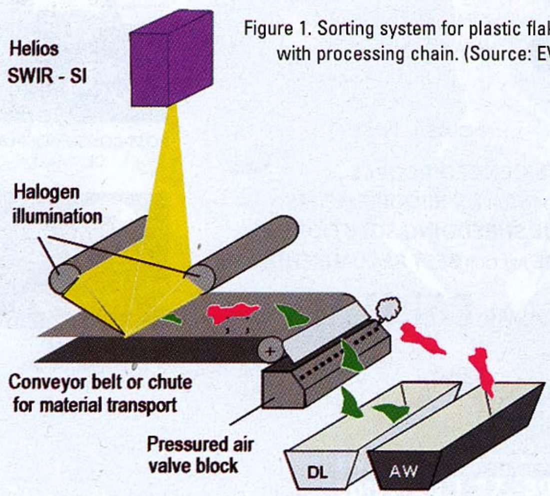

Figure 1. Sorting system for plastic flakes with processing chain. (Source: EVK)

Automated recycling

In Germany and the EU, both the waste electrical equipment regulations (EU Directives WEEE and RoHS) and the implementation of rewards for the scrapping of older automobiles have led to the current push to recycle base material components instead of sending them to landfill. As a consequence, there is a need to automate the recycling effort to make it cost-effective and therefore beneficial. To be economical, however, automated recycling systems are programmed for the effective separation of predetermined materials, or groups of materials, depending on the material mix. Appropriate sensors are the key to capturing the common characteristics of these materials for classification.

Appropriate separation systems

To effectively automate separation, the materials on hand are first shredded into smaller pieces or flakes of a size (3-5 cm for plastic parts) which can be easily handled by the separation unit. Figure 1 (left) shows the typical layout of a pneumatic separator. The shredded materials – singulated if possible – are placed on a conveyor belt, and this material stream goes under the sensor at a constant speed. The sensor captures the material's properties so that the evaluation and control unit can then do a quick pre-processing and feature extraction for a particular material classification. Based on this evaluation, one or more high-pressure valves in an air valve block will blow the selected parts into a collection tub (called an accepted ware or AW) or a waste tub (called a dump load or DL) .

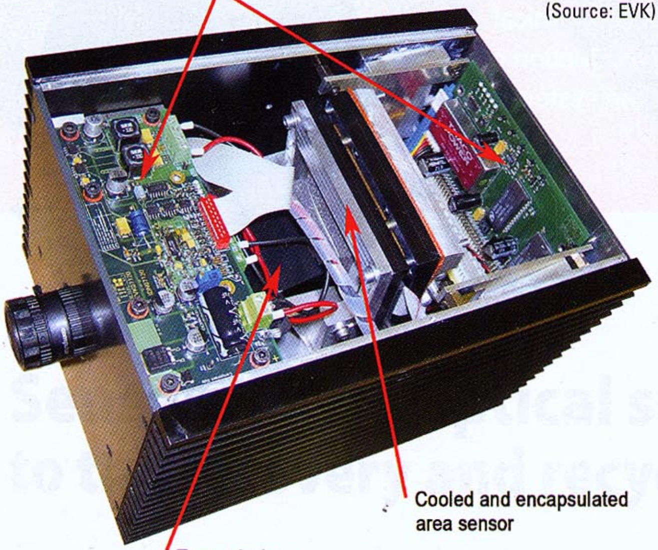

Figure 2. Compact configuration of a smart SWIR spectral camera (Source: EVK)

Optimum system configuration

To the human eye, most plastic parts look alike. Only inspecting them in the short wave infrared (SWIR) realm at wavelengths between 1.0 and 2.5 micrometer (µm) will reveal the actual differences. Analysing these spectral curves enables the classification of different materials. Figure 2 (above) shows a system suited to this task.

At its optical input (on the left), the system features a 2D transmission spectrometer, which yields the spectrum at each point of a scan line across the moving conveyor belt. A cooled and encapsulated area sensor in indium-gallium-arsenic-technology (InGaAs) covering the standard SWIR wavelength area of 0.9-1.7 µm, captures this two-dimensional information and delivers it to the FPGA (field programmable gate array) pre-processing circuitry.

Accurately capturing the spectral intensity puts high demands on the SWIR sensor resolution. Spatial resolution, on the other hand, can be increased to a high degree by simply connecting several receiver units in parallel. The optimum resolution value, among other factors, depends on the conveyor speed.

Key component: the SWIR sensor

The key components of such imaging spectroscopy in the near infrared are sensor arrays in InGaAs technology, which yield a high resolution at minimal dark current. InGaAs area sensors will deliver good results in the SWIR up to a wavelength of 1.7 µm, even at room temperature. When thermoelectrically (TE) cooled, InGaAs sensors have significant advantages up to a wavelength of 2.5 µm, serving as a viable alternative to mercury-cadmium-tellurium (HgCdTe) detectors. InGaAs detectors' high sensitivity and small dimensions enable the construction of compact SWIR cameras and image capture systems using commercially available components.

InGaAs sensor arrays are manufactured by metal-organic gas-phase epitaxy (MOCVD), a well known process for semiconductor manufacturing. Thin layers of InGaAs are deposited on substrates of matching crystal grid constant, such as indium-phosphide (InP). Since the manufacture of SWIR sensors is quite similar to standard processes in silicon semiconductor production, this is cost-efficient at high yields.

InGaAs sensors are not particularly suited to locating their readout circuitry and logic functions on the same chip. Therefore, sensor array and read-out circuitry are built-in extra elements, with multi-pole interconnect. Figure 4 (on page 24) shows four different ways of interconnect: first, as a direct hybrid where the sensor array is bumped to the readout circuit (a); second as indirect hybrid with bumped array and readout on a common substrate (b); third as a sensor/readout IC with wirebond for single processing (c) and fourth as a 3D Z-structure, which bonds the sensor array along the edges of stacks of thinned read-out circuits (d).

Various camera designs

Measuring just 5 x 5 x 5 cm, the XS-FPA-1.7-320 SWIR camera is fitted with an uncooled sensor array of 320 x 256 pixels (top camera shown in Figure 3, right). Two cameras below, the high-sensitivity XEVA-FPA-1.7-320 is shown, having the same resolution but fitted with one- to three-stage thermoelectric cooling.

When it comes to assembling an application-specific SWIR camera system solution, the method is not limited to standard versus in-house design. A better way is to draw on the expertise of a vendor such as Xenics to develop a specific sensor plus specific read-out circuit. The result is an optimum solution for the application, delivering significantly enhanced system performance – without necessarily increasing the cost.

A typical example is the water-cooled FPA camera (shown in Figure 3 at the bottom). This is a derivative of the XEVA-FPA-1.7-320 series for a 60 Hz frame rate, offering identical functionality but with

Figure 3. Infrared cameras of different approaches can cover broad application fields.

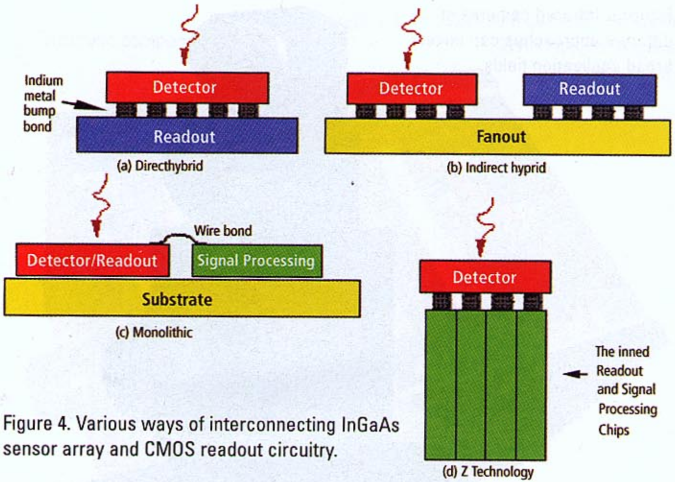

Figure 4. Various ways of interconnecting InGaAs sensor array and CMOS readout circuitry.

a cooling water connection replacing the cooling fan. The main driver for this development was a microscope application forbidding fan vibration so it had to be cooled another way.

Mastering problem cases

The extraordinary flexibility in terms of sensor and camera configuration offered by Xenics can be very helpful when solving specific application-based problems in sorting tasks. One such problem is caused by black plastic parts. SWIR spectroscopy analyses the light reflected by the objects to be examined. Plastic parts from disposed electrical equipment and shredded automobiles often happen to be dark coloured for design reasons, meaning they deliver only weak optical responses. In those cases a spectral combination of SWIR sensing and visible colour capture is helpful.

A possible cause of error, however, can be the strong absorption by the sensor substrate of visible and near-infrared (up to 0.9 µm) radiation. Therefore, the substrate is substantially thinned using a novel method, which prevents any damage to the InGaAs detector by additional layers of indium-gallium-arsenic-phosphide (InGaAsP) underneath the photo diodes. This serves as an etch stop within the surrounding InP. In a follow-up etch step with hydrochloric acid (HCl) the InP substrate is selectively removed exactly up to the InGaAsP etch-stop layer. This process will thin the sensor chip to just 5 µm. The sensor becomes transparent to visible light, enabling it to cover the broad wavelength area from 0.4 µm to 1.7 µm.

Conclusion

Automated material sorting still is not attractive to many recyclers, because it currently doesn't deliver a reasonable return on investment. Sensor technologies, on the other hand, are progressing very rapidly and the necessary computing power is becoming cheaper all the time. In the mid-term, over the next few years, the prognosis is that economical solutions in automated material sorting will broadly penetrate the market. Companies working today on key technologies in this realm (SWIR sensors, FPGAs and DSPs), developing proprietary high-performance algorithms and creating practical systems will have the advantage of quickly gearing up and gaining a significant market share.

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