PRESS RELEASE

Laser technology and AI boost the circular economy

The recycling industry is increasingly relying on laser-induced breakdown spectroscopy (LIBS) to identify reusable raw materials in waste streams. The Fraunhofer Institute for Laser Technology ILT in Aachen is playing a leading role in developing this highly precise technology for element analysis and is continuously expanding its range of applications.

The transformation to a circular economy is in full swing. Recycling rates for raw materials such as paper or aluminum from packaging are already above 90 percent. In order to close further material cycles, however, the recycling industry needs sensor-based processes that can identify a great deal of different recyclable materials in waste streams not only reliably, but also fully automatically and at high speed.

Real recycling rates still too low

A fundamental goal of the circular economy is to reuse valuable raw materials – if at all possible – without downcycling. The most important prerequisite for this is separation by type. However, this is precisely where there are still technological gaps in many cases. For example, Germany is considered exemplary when it comes to implementing the EU End-of-Life Vehicles Directive and complies with the specified recycling rate of 95% for end-of-life vehicles; in the current reporting year (2021), it was 97.5%. However, in addition to material recycling, this rate also includes energy recycling, i.e. incinerating materials that are not recyclable or for which the recovery processes through to reuse are not worthwhile. When recycled for energy, these materials are at least used to generate electricity and heat.

Of this 97.5 percent of end-of-life vehicles, 86.6 percent of the material was recently recycled according to the German Federal Environment Agency (UBA). However, there is also room for improvement here. The UBA criticizes the fact that material recycling all too often leads to "downcycling": Recovered secondary materials are used in applications that do not correspond to their original value. For example, high-quality automotive steel from cars is often reused as construction steel. Valuable car glass often ends up as insulation material or filling material for landfills since coatings on the glass are difficult to remove; making them easier to downcycle. For non-metallic materials, value-preserving recycling is the exception rather than the rule: According to the UBA, only 13.5 percent of plastics and 8.3 percent of glass are recycled at all.

Press contact
Petra Nolis M.A. | Head of the Communications Group | Telephone +49 241 8906-662 | petra.nolis@ilt.fraunhofer.de
Fraunhofer Institute for Laser Technology ILT | Steinbachstraße 15 | 52074 Aachen, Germany | www.ilt.fraunhofer.de

Laser-based sensor technology helps to close material cycles

Fraunhofer ILT has a solution that can significantly improve recycling and minimize high-loss downcycling through highly efficient, reliable and differentiated analyses of the valuable materials contained in waste streams: Laser-induced breakdown spectroscopy (LIBS) is one of the key technologies for an economy based on actual material cycles. This is because the highly accurate, real-time spectroscopic determination of which chemical elements materials contain enables differentiated separation by type.

For spectroscopy, a high-energy laser pulse excites the surface of the material. This creates a plasma in which the chemical bonds between the elements of the material are broken up. The atomic fingerprint is different for each material and can be read spectroscopically at the moment when the atoms return to their stable state: They emit light in specific wavelengths, from which the respective element can be deduced. LIBS, therefore, reveals the exact chemical composition of the laser-excited material in fractions of a second. The non-contact method can be applied to all materials, regardless of whether they are solids, liquids or gases.

Dr. Cord Fricke-Begemann's materials analysis working group at Fraunhofer ILT is driving forward the development of inline processes based on LIBS technology to pave the way for the unmixed recovery of metals from mountains of waste and scrap. "Using a scanner-based selection of measuring points and around 100 LIBS measurements per second, we can very quickly create two-dimensional representations of the element distribution. Based on these spatially resolved analyses, we are able to detect technology metals in electronic waste and thus, for example, return valuable tantalum from capacitors to the material cycle," explains the Fraunhofer ILT scientist.

Aluminum recycling: laser ensures higher purity

Particularly for complex material compositions – as in electronic waste or end-of-life vehicles – one-to-one recycling depends crucially on the accurate, spatially resolved determination and separation of the individual material fractions. Only if recycling companies are able to determine exact chemical compositions in real time and sort waste on this basis will efficient reuse without downcycling be feasible. And this is what LIBS lays the foundation for: the automated, unmixed separation of a wide range of metal alloys using non-contact, laser-based, quasi-real-time analysis of materials. The process helps users determines how the materials can be used based on product, and, thus, identifies their full value. This applies to high-quality metals in electronic scrap as well as special alloys in toolmaking or the wrought aluminum alloys widely used in automotive engineering.

However, the differentiated analysis of recyclable materials using LIBS is not only the basis for truly closed material flows without downcycling. It also paves the way for accelerated sorting processes and, in conjunction with automated sorting technology, contributes to their cost-effectiveness. “We can process much more scrap in a shorter time than with traditional manual sorting and also achieve genuine sorting purity,” says Fricke-Begemann, summarizing the advantages.

As part of the PLUS project funded by the Federal Ministry of Education and Research (BMBF), Fraunhofer ILT and Cronimet Ferroleg GmbH from Karlsruhe have made LIBS the basis for a new type of process that uses laser-based analysis for a special type of scrap. “These are worn-out drilling, turning and milling tools, which are collected separately in industry. Our project has addressed the special alloys processed in them,” reports Fricke-Begemann. The materials are valuable since they contain a high amount of cobalt, molybdenum and tungsten, and are particularly attractive for single-origin recycling. This is because, like all metals, they can be melted down as often as required and reprocessed into high-quality cutting tools without any loss of quality. In the federally funded project, the partners were able to provide proof of this and demonstrate that the LIBS analysis is reliable. Ultimately, they were able to automate and greatly accelerate the separation process by combining LIBS and robotics. The spectroscopic process identifies more than 20 different alloy elements, even in tiny scrap parts; the robot picks them up and sorts them accordingly. It is the blueprint for fully automated recycling, which can decisively contribute to making recycling processes more efficient.

Laser as a detective: Where are lithium, phosphorus and graphite hiding?

LIBS can also play a key role in the recycling of batteries, an ability that will soon be essential since the mobility sector is slowly transitioning to electricity and the stationary storage requirements are sharply increasing. ACROBAT, an international project that has been running since fall 2022, aims to increase the proportion of critical raw materials recovered from recycled lithium iron phosphate batteries (LFP batteries) to more than 90 percent by 2030. To date, there has been a lack of practicable solutions for recovering raw materials such as lithium, phosphorus and graphite from the anodes and cathodes of battery cells. “With LIBS, we have a tried and tested approach that we can use to measure the quantity, purity and distribution of the valuable materials contained and derive suitable strategies for their reprocessing,” reports Fricke-Begemann.

The targeted combination of LIBS with digital technologies such as digital twins or artificial intelligence (AI) and machine learning opens up completely new possibilities for the recycling industry. “The use of AI is particularly promising due to the variety of materials, the amount of data being generated and the speed at which materials need to be classified during the ongoing process," says Fricke-Begemann. Especially as it is foreseeable that the industry's tasks will become increasingly complex as the transformation towards a circular economy progresses. In the future, combining LIBS and AI tools could prove to be a real game changer when it comes to detecting and retrieving valuable materials for recycling, not only in pre-sorted industrial waste, but also in household waste. This is also because appropriately trained AI algorithms are able to process data streams from several optical sensors working in parallel. This would open the door to high sorting accuracy at maximum process speeds.

AI and LIBS as pioneers of a genuine circular economy

The experts in Aachen are using the innovative combination of LIBS technology and 3D sensor technology to spatially determine the exact position and orientation of valuable materials. "This means we know exactly where we need to direct the laser beam in order to identify the material," explains the Fraunhofer ILT expert. Detailed information on the location, quality and exact chemical composition of the respective waste is then available within fractions of a second. In the future, accompanying regulatory measures such as the digital product passport will further increase transparency regarding the materials used along the often global supply chains.

Nevertheless, the transformation to a circular economy remains a Herculean task. "We will be able to detect many more substances by 2030," Fricke-Begemann is certain. But whether it will be possible by then to actually completely recycle valuable raw materials from end-of-life vehicles, electronic waste and other waste streams and close the corresponding material cycles is questionable. However, LIBS is pointing in the right direction and could prove to be an enabler of genuine closed-loop processes without downcycling.

Image 1:
Laser-induced breakdown spectroscopy LIBS detects valuable alloys in scrap metal, which robots separate by type. The process creates the basis for closed material cycles without downcycling.
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Image 2:
Closed material cycles without downcycling pave the way to the circular economy. With the LIBS process, the Fraunhofer ILT is developing a key technological building block for this.
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Image 3:
Analysis of metal scrap by laser-induced breakdown spectroscopy LIBS.
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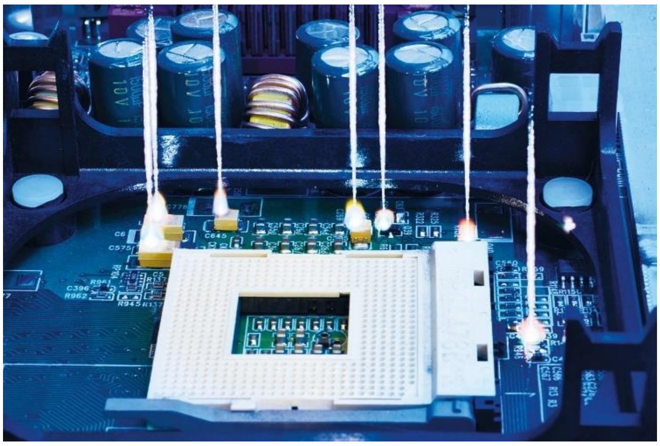

Image 4:
Components or modules are analyzed with LIBS in order to secure valuable raw materials in electronic waste. After excitation with a high-energy laser pulse, plasma is formed from which the "atomic fingerprint" of the material can be read using spectroscopy.
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FRAUNHOFER INSTITUTE FOR LASERTECHNOLOGY ILT

Professional contact

Dr. Cord Fricke-Begemann
Head of the Group Material Analysis
Telephone +49 241 8906-196
cord.fricke-begemann@ilt.fraunhofer.de

Prof. Carlo Holly
Head of the Department Data Science and Measurement Technology
Telephone +49 241 8906-142
carlo.holly@tos.rwth-aachen.de

Fraunhofer Institute for Laser Technology ILT
Steinbachstraße 15
52074 Aachen, Germany
www.ilt.fraunhofer.de