Boosting efficiency and data quality – lasers for LIBS aluminum recycling

Flexible MOPA lasers from Neolase improve aluminum sorting speed and accuracy

Torsten Ledig

© Maria - stock.adobe.com

Aluminum recycling is crucial for both economic and ecological reasons, offering significant energy savings and reducing raw material scarcity. Among various techniques for sorting aluminum scrap, laser-induced breakdown spectroscopy (LIBS) stands out for its rapid and precise identification of elemental composition. The MOPA approach from Neolase enhances LIBS performance by providing high energies and precise control over pulse parameters, improving data quality and sorting efficiency.

The importance of the recycling industry has heightened in recent years for both environmental and economic reasons. The transition to a sustainable, circular economy is progressing, aiming to minimize downcycling – reusing secondary materials below their original value. At the same time, pressure on supply chains, rising prices, and the scarcity of raw materials make recycled material an attractive, cost-effective, and readily available alternative. Recycling aluminum is particularly appealing due to its high value, widespread use, almost complete recyclability without loss of properties, and significant energy savings.

However, avoiding downcycling requires scrap metal pieces to be precisely sorted into individual alloys. With aluminum, the differences in material composition between various classes are minimal but significantly impact selling prices. Accurate sorting also makes further processing and melting easier, resulting in higher product quality and, consequently, higher selling prices. To make this economically feasible, recycling companies need automated solutions for quick and accurate sorting.

Analyzing and sorting scrap aluminum

Analyzing the exact classes of the individual metal pieces is a challenging process. Besides the small differences in material composition, aluminum is often mixed with other metals during production, while paint, coatings, or dirt on the surface can make it even more difficult to determine the exact alloy. As available technologies for metal sorting usually detect only certain elements, they are often combined in a multistage process.

The first step is typically to isolate aluminum regardless of the exact class.

Contamination from iron, steel, or heavier metals can be removed by magnetic separation, which divides ferrous from non-ferrous metals, or density separation, which separates aluminum from heavier metals regardless of their ferrous content. X-ray transmission (XRT) is another technique that separates metals by density and thickness. If aluminum scrap needs to be extracted from a stream of mixed waste, eddy current separation can be employed. By generating eddy currents in the aluminum, a repelling force is created that separates the aluminum from other materials with different electrical conductivity.

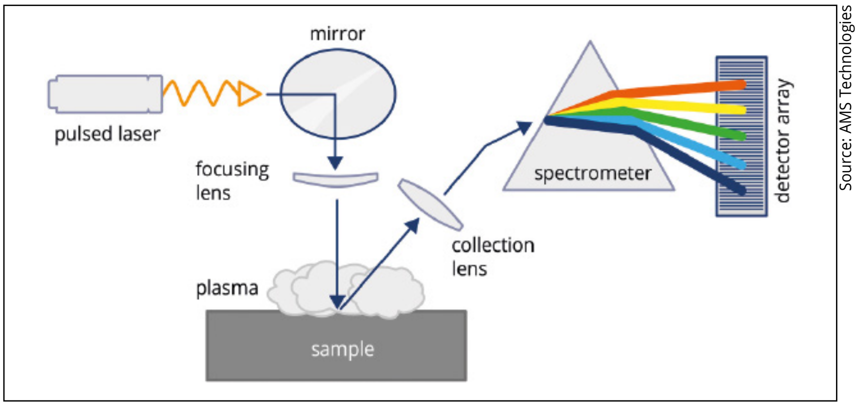
However, as all aluminum alloys are non-ferrous and have a similar density, further processing with different techniques is needed. X-ray fluorescence (XRF) analyzes the elemental composition of metals and works well for sorting different aluminum alloys. XRF is particularly useful to differentiate between various alloyed elements such as copper and zinc, which are both key components in many aluminum alloys.

Laser-induced breakdown spectroscopy (LIBS) is a rapid and precise method of identifying the elemental composition of metals, even in complex mixtures, by analyzing the light emitted from a plasma created by a focused laser pulse. LIBS is particularly useful for sorting metals with similar densities but different elemental compositions, such as various aluminum alloys. In contrast to XRF, LIBS is particularly useful to detect magnesium, another key component in many aluminum alloys.

As XRF and LIBS have their individual strengths in detecting different elements, they are often used in combination or sequentially. LIBS typically offers higher speed and accuracy, as XRF may require more time for analysis and may be less precise in detecting slight variations in alloys. LIBS is also less sensitive to surface contamination such as dirt, paint, or other coatings because the laser can reach the underlying metal for accurate data. XRF systems usually cannot match the accuracy of LIBS systems when analyzing light elements with low atomic numbers (e.g. Be, Li, Al, or Si) due to insufficient usable data.

Laser-induced breakdown spectroscopy

Typically, LIBS systems use a high-energy pulsed laser as the excitation source and focus the laser beam through a lens to generate plasma on the metal surface.



Schematic of a LIBS system

The plasma emits light, which is then collected through a lens and guided into a spectrometer. In the detector array, the spectrum of the light is analyzed to determine the exact alloy of the scrap metal. An automatic sorting mechanism then divides the different alloy classes either for one or more additional sorting procedures or for packing and shipping for further processing. Depending on the exact setup, techniques such as three-dimensional object recognition can also be employed.

Challenges for lasers in aluminum recycling

The main challenge for system providers is to realize fully automated sorting at a speed that allows profitable operation in scrapyards. This creates multiple requirements of the laser. First, the laser must be powerful enough to provide sufficient plasma generation, even on contaminated or coated surfaces. Second, a high repetition rate and high accuracy maximize the throughput in tons per hour, allowing the sorting machine to operate at sufficient speed and minimizing the need for repeated sorting runs. Third, the laser system needs to balance compactness for easy integration into the sorting machine with long-term stability and durability for continuous operation in a harsh environment, without deviations in accuracy or extended downtimes for maintenance.

Laser systems for LIBS sorting

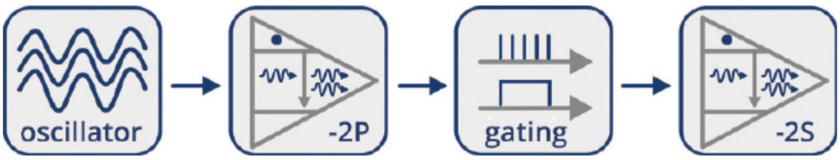
Several laser technologies are available to solve these challenges. Q-switched lasers offer high peak power and short pulse duration, though with somewhat limited control over pulse parameters. Fiber lasers with high repetition rates and excellent beam quality are another option, but typically limited in peak power. Diode-pumped solid-state (DPSS) lasers are compact and provide high-quality beams. For LIBS purposes, the master oscillator and power amplifier (MOPA) architecture offers high energies and the most control over pulse duration and repetition rate, providing the highest flexibility to optimize the LIBS process.

For a concrete example of such a MOPA system, Neolase, an AMS Technologies company, uses a commercial fiber laser or a modulated laser diode as a seeder, combined with the company's own neoVAN DPSS amplifier modules and a modulator to gate the laser pulses into the application.

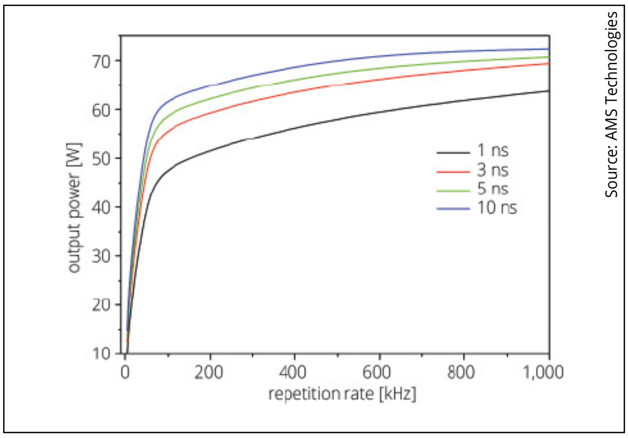
In a typical configuration suitable for LIBS-based aluminum recycling, such a MOPA system can achieve repetition rates up to 1 MHz, more than 1 MW peak power, and an output power of up to 75 W. Several millijoules of pulse energy and tunable pulse durations from about 5 to 100 ns enable a wide parameter range for different metal alloys.

Improving data quality and efficiency with MOPA lasers

The main advantage of DPSS amplifiers over fiber lasers is their higher pulse peak power, which is essential to create a strong plasma plume on the scrap pieces. Neolase has also been working on further optimizations that use the flexibility of the MOPA architecture and can significantly improve data quality and efficiency in the sorting process.



Flux diagram of the Neolase MOPA system



Repetition rate of the Neolase MOPA system

A neoMOS laser head from Neolase

A preablation pulse is an additional laser pulse immediately before the actual analysis pulse. It removes dirt, paint, and other coatings from the scrap metal pieces, helping to achieve a cleaner signal. This is only possible if the laser has a sufficiently high repetition rate to hit the same scrap piece twice in a very short time before the piece moves away on the conveyor belt. The spectrum of available wavelengths enables exact calibration for individual alloys, optimizing plasma generation and in turn leading to a more intense signal that is easier and more accurate to analyze.

Pulse shaping is another way to improve the signal quality. The pulse duration can be adjusted by the seed laser and further shaped by the gain dynamics of the amplifier stages. As a result, typical pulses will have a peak lasting a few nanoseconds, followed by a declining tail with an adjustable slope. For applications that require high peak power, this shaping helps to initiate the laser process and maintain it for a specific time, which can be adjusted by changing the trailing part. The benefit for LIBS is that the plasma plume remains stable for a longer time, resulting in a stronger and more intense signal that is easier to analyze and provides more accurate data.

Typical long term power stability has been determined to be <1 % RMS over an eight-hour period. This not only enables stable operation throughout the day but also allows for the exchange of information between several LIBS systems because the data quality is uniform and stable. This saves time and effort in calibrating the individual systems.

With a beam quality factor M^2 of less than 1.3 in all power modes and a beam roundness of more than 95 %, the necessary predictability of the laser beam propagation is ensured. The energy required to generate the plasma is strongly dependent upon the diameter of the beam focus: the smaller the focus diameter, the lower the pulse energy required to generate plasma, leading to higher fluence and a greater possible working distance.

Compactness and reliability

The compact system, based on the customized MOPA architecture from Neolase, has a footprint of only 617 × 412 mm. It includes a water cooler and a 4U laser electronic unit for parameter control. The system is controlled with neoCON software and complies with OPC-UA to set and monitor all relevant parameters. MOPA systems with DPSS amplifiers from Neolase are used in various applications and have demonstrated long-term reliability, with some examples operating continuously for over ten years.

Conclusion

In conclusion, LIBS sorting, and particularly the use of DPSS amplifiers and MOPA architecture, significantly improves the efficiency and accuracy of aluminum recycling processes. By addressing challenges such as surface contamination and the need for precise sorting, these systems ensure higher quality recycled materials, contribute to a more sustainable circular economy, and help recycling companies to work profitably. The combination of compactness, reliability, and innovative techniques such as preablation pulses and pulse shaping positions these laser systems as essential tools for modern recycling operations. As the industry continues to evolve, these technologies will play a crucial role in meeting the growing demand for high-quality recycled aluminum.

DOI: 10.1002/phvs.202500013

Author

Torsten Ledig has more than two decades of professional experience with laser systems and optical solutions. He joined AMS Technologies in 2007 and has been promoted to senior sales manager for the optical technologies. He studied physics and did his doctorate in kinetic processes in gas discharges at the Friedrich Schiller University Jena (FSU).

AMS Technologies AG, Dr. Torsten Ledig, Fraunhoferstr. 22, 82152 Planegg, Germany; phone: +49 89 89577-549, e-mail: tledig@amstechnologies.com, Web: www.ams-technologies.com, linkedin.com/in/torsten-ledig-a2580026 linkedin.com/company/ams-technologies-ag

Company