



*Dr. Cord Fricke-Begemann  
Fraunhofer-Institut für Lasertechnik  
Aachen/Deutschland  
www.ilt.fraunhofer.de*

*Cord Fricke-Begemann, Diplomphysiker,  
promovierte im Bereich optische Fernerkundung  
der Atmosphäre und entwickelt seit 2005  
neue Verfahren zur Laser-Materialanalyse am  
Fraunhofer-Institut für Lasertechnik.*

*Dr. Reinhard Noll  
Kompetenzfeldleiter Messtechnik  
Fraunhofer-Institut für Lasertechnik  
Aachen/Deutschland  
www.ilt.fraunhofer.de*

*Univ.-Prof. Dr.-Ing. Hermann Wotruba  
RWTH Aachen University, Leiter des  
Lehrgebiets Aufbereitung mineralischer  
Rohstoffe  
Aachen/Deutschland  
www.amr.rwth-aachen.de*

*Dipl.-Ing. Christian Schmitz  
RWTH Aachen University, Lehrgebiet  
Aufbereitung mineralischer Rohstoffe  
Aachen/Deutschland  
www.amr.rwth-aachen.de*

## Fast and flexible

### Laser-assisted sorting of minerals

**Summary:** For determination of the composition of minerals, at the Fraunhofer Institute for Laser Technology a laser method was developed that can be used for the fast online analysis of a wide range of raw materials. The non-contact multi-element analysis with which a direct sorting criterion can be determined, also enables automatic and economic single-particle sorting of rocks and ores. On a demonstration rig, an efficient reduction of the MgO content of limestone production samples could be realized.

#### 1 Introduction

For efficient exploitation of natural raw material deposits and high-quality processing, for many, especially complexly structured and inhomogeneous deposits, a sorting of the extracted raw materials is required. The sorting processes used in the processing of minerals separate the material to be sorted based on one sorting criterion, which only indirectly correlates with the chemical composition of the material. For example, ores are separated according to their density or their surface wettability. For a sorting that actually separates the material directly according to the required criterion, e.g.

value material or impurity content, a characterization of the material, however, is necessary, for which suitable measuring technologies must be available [1].

Laser light is predestined for the online measurement of physical and chemical variables, like, for example, the geometry of objects or their material composition. Laser measurement methods work fast and over distances of several centimetres to metres. The measured object can be analysed direct in a production line, without the need to remove it from or otherwise influence the process flow. The capability of online



1 Laser-induced plasma on a limestone

analysis opens up new possibilities for optimized process control, which cannot be realized with conventional methods.

In a cooperative project with industry partners and funding from Germany's Federal Ministry of Economics and Technology [2], the Fraunhofer-Institute of Laser Technology and the Department of Mineral Processing at RWTH Aachen University have developed a process that enables laser-assisted online analysis of minerals and combines this with technology for single-particle sorting of the products. The process approach was in the first instance realized for the processing of limestone and can also be used in many other applications.

## 2 Material analysis with lasers

For fast element analysis of many materials, laser direct analysis based on emission spectrometry of laser-induced plasmas is suitable [3]. If the beam of a pulsed laser is focussed on a measured object, power densities in the range of  $\text{GW}/\text{cm}^2$  are reached locally for short time. These are sufficient to vaporize every material, to dissolve the chemical bonds and heat the material to temperatures above  $10000^\circ\text{C}$ . In this state, the material emits light in its specific spectral lines, which is analysed with a spectrometer. Such laser-induced plasmas on limestone are shown in Fig. 1. The spectrally resolved detection of the emitted line radiation allows the qualitative and quantitative determination of the composi-

tion of the object. The purely optical excitation and simultaneous analysis of the spectral lines enable the analysis of metallic and non-conductive material within just a few microseconds. It also enables the analysis of fast-moving objects. Laser-induced breakdown spectroscopy (LIBS), is a method for elemental analysis, which is also described as laser plasma spectroscopy or laser-OES. Typical characteristic values and data of laser direct analysis with this method of measurement are listed in Table 1.



2 Singled limestone particles on a belt conveyor

Table 1: Typical characteristics and data of the laser direct analysis

Characteristic	Data
Material	mineral, metallic, oxide, organic, solid or liquid
Clear distance between lens and workpiece	1 cm – 1 m
Lateral resolution	10 – 300 $\mu\text{m}$
Measurement time	< 100 $\mu\text{s}$
Simultaneously detected elements	48, all elements can be detected
Sensitivity of detection	100 ppb – 1000 ppm
Measurement rate	0,1 – 1000 Hz

The Fraunhofer ILT has already introduced the LIBS method to different industrial applications, especially for process control. The method has also proven effective for fully automatic measurements [4]. It has, for example, already been used for the analysis of metallic raw materials for material recycling [5] and is available thanks to further development for use in mineral processing. To obtain quantitative analysis results, it is necessary to calibrate the process. For this purpose, rock samples were used from which one part was separated and ground. This part was investigated with the established standard method of X-ray fluorescence analysis (XRF). The values for the rock samples measured with the laser were compared with these values and a calibration function calculated for the element concentrations to be measured.

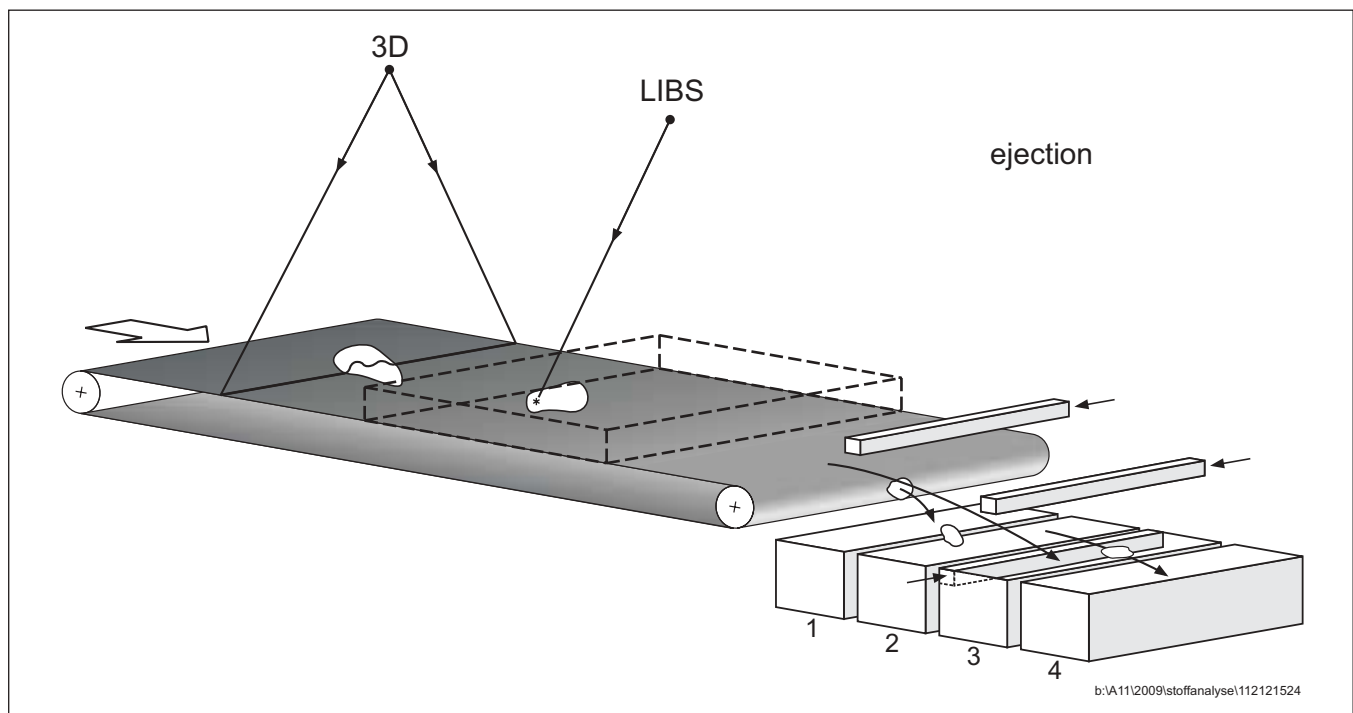
### 3 Online analysis and raw materials sorting

Sorting is often necessary to obtain saleable or to produce higher grade products from the minerals extracted from a

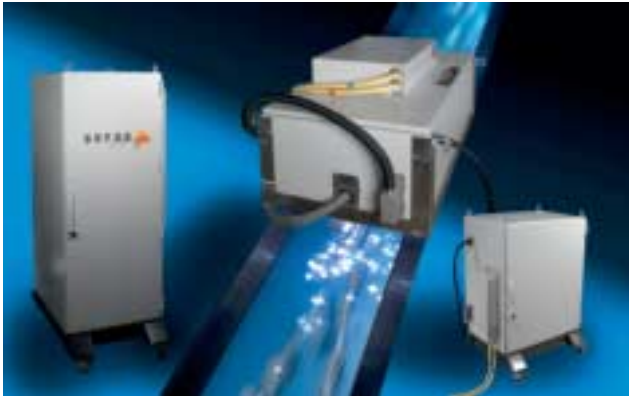
deposit. The aim of this sorting is, for example, to concentrate the value content in the product, to reduce the mass flow for downstream processes or to comply with a limit for a product impurity.

A consistent product within the given specifications is to be produced, while the loss in value material minimized. To meet these requirements as effectively as possible, the concept of single particle sorting with full laser analysis of all single particles was pursued.

The material to be sorted with a particle size of 50–150 mm (Fig. 2) is first separated into single particles and then fed onto a belt conveyor with a belt speed of 3 m/s. As shown in Fig. 3, the single particles on the belt are identified optically and their position and geometry are determined. Then the laser beam is specifically directed at the single particles for analysis. The results of the analysis are evaluated in fractions of a second and a sorting decision is made for every



3 Schematic of the laser sorting system. Rock particles move on a belt conveyor with speeds up to 3 m/s from left to right. A 3D camera measures position and shape of the particles and the beam of the laser analysis module (LIBS) determines the material composition. Depending on the measured results, the particles are discharged by means of compressed air jets in various fractions 1–4



4 Laser unit for single particle analysis of rocks on belt conveyors; Left: Control cabinet, Centre/top: Laser module, Centre/bottom: Belt conveyor with sorting material and laser-induced plasmas (long-term exposition), Right: Spectrometer module

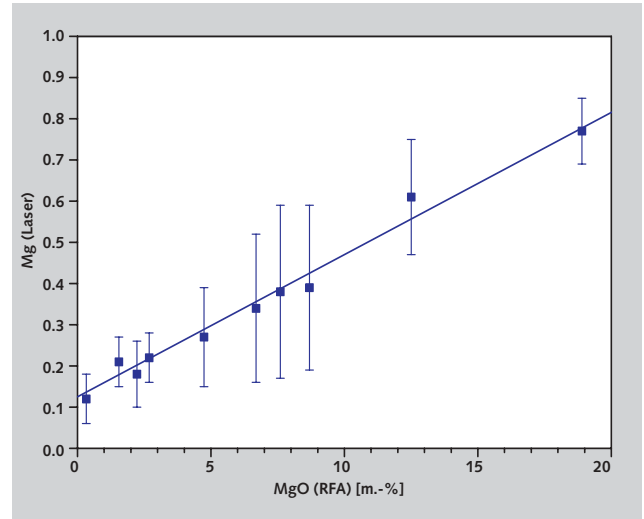
single particle. Based on the analysis and position information, the compressed air jets in the discharge unit are actuated and controlled such that the individual particles can be separated and discharged in two or more fractions. Thanks to the fast direct analysis, the different stages in the sorting process can be arranged practically seamlessly downstream of each other. The conveying distance from 3D identification to the end of the belt is less than 2 m. So that the individual particles remain still on the belt, a sufficient stabilization zone must also be installed upstream of the sorting unit.

Fig. 4 shows the laser analysis unit for single-particle sorting. The laser module is installed above the belt conveyor. Laser, spectrometer and control module are rugged, designed to be suitable for use in industry and for use in surface mine/quarry conditions. With a measurement rate of 15 Hz, for the particle size range from 50–150 mm, throughput rates up to 100 t/h can be achieved. Further developments of the components used are intended to enable 100 individual measurements per second so that even with a smaller particle size or irregular loading, economic throughput rates can be achieved.

#### 4 Results

To use laser direct analysis for sorting minerals, specific process characteristics were examined and further developed. The work was initially concentrated on one application in limestone processing. Of primary importance here is the magnesium content, so as to differentiate pure limestone from dolomitic rock. In the analysis of production samples, a MgO content in the range from 0 to over 20 % was covered. A value of 5 % MgO can be taken as a typical maximum value for the usability of the aggregate for cement and steel production. The work presented here is therefore limited to the magnesium content. Further investigations have shown that other clay minerals and extraneous rocks can also be determined.

For fundamental studies, production samples from several limestone quarries in three different countries were available. A measurement and evaluation method could be developed that can determine the MgO content irrespective of the



5 Calibration of the laser measured values for Mg with XRF reference analyses

deposit. Differences in the surface condition of the rocks lead to changes in the interaction between the laser and the sample. Provision for this can be made in the evaluation with compensation measures that use the different parts of the spectral measurement signal.

Laser direct analysis consists of a local analysis of the sample surface. As in all measurement methods with a low penetration depth into the material (e.g., XRF, LIF, NIR, LIBS), dust sticking to the particle surface can interfere with the analysis. The high-energy laser beam used in this case results in local material removal. This can be used to selectively clean the sample surface prior to analysis. An approach was developed that allows such local cleaning even of moving objects at a belt speed of 3 m/s. With this patented approach, the precision of the laser direct analysis could be improved so that no noticeable disturbances caused by surface dust could be observed.

The measurement process was calibrated as described above with production samples whose MgO content had been determined with X-ray fluorescence analysis. Fig. 5 shows a calibration curve obtained from static samples. Measurements were taken at 10 measurement points distributed over the surface of the samples, from which the sample for XRF was also taken. The LIBS measurements can be linearly calibrated to the XRF with a correlation coefficient  $R^2$  of 0.99, which corresponds to a process standard deviation of 0.74 % MgO. The high standard deviation of the individual measurements (error bars in Fig. 5) can be attributed to the inhomogeneity of the samples. For measurements on moving specimens, the process standard deviation rises to around 1.3 % MgO, since here measurements are taken at other automatically selected points of the specimens, which do not represent the same spatial averaging as the XRF analyses. The scattering of the individual measured values is not critical for the characterization of the composition of a material stream as here based on temporal averaging, a conclusion can be made with regard to the mean content. How far localized laser direct

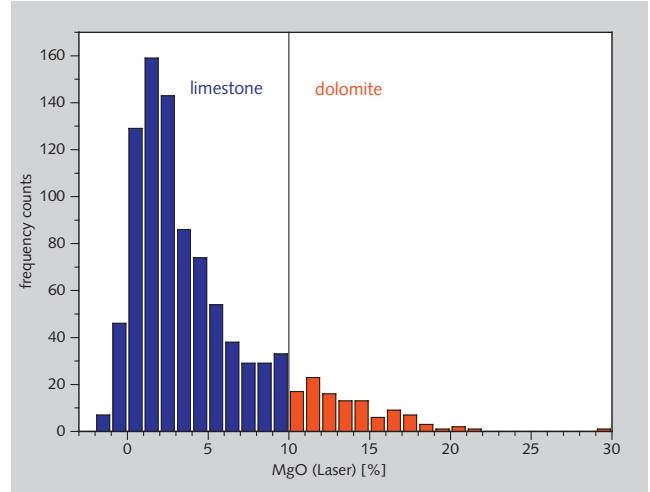


Photo: RWTH-AMR

6 Limestone quarry in Austria

analysis is sufficiently representative for effective single particle sorting can only be established in sorting tests in realistic conditions.

For this purpose, a demonstration rig was set up according to the concept described above, which enables the sorting of production batches in the testing centre. Without further pretreatment, a batch of 435 kg of unknown composition from an Austrian limestone quarry (Fig. 6) was separated into two fractions on the basis of their MgO content; these can be classed as limestone and dolomite. As a threshold value for the classification, in the following example, a MgO content of 10 % was chosen. The sorted fractions were then comminuted as a whole and homogenized so that based on a representative specimen the average composition of the fraction could be determined with XRF. Fig. 7 shows the frequency of the measured MgO content of the single particles based on a single LIBS measurement. Most rocks have around 2 % MgO. The distribution soon drops to higher contents, extending to around 20 % MgO. Classification



7 Distribution of the measured Mg concentrations and threshold value for the grouping

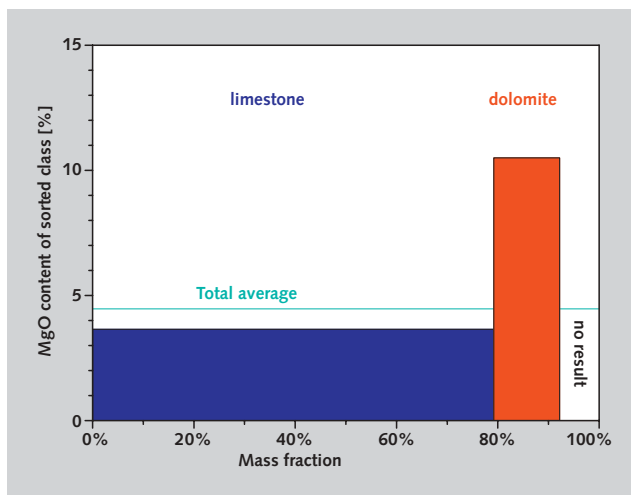
according to the defined limit leads to a classification of 79 % (weight) as limestone and 13 % as dolomite (Fig. 8). A content of 8 % could not be classified, mainly because the stabilization zone was too short, so that the particles did not lie still on the belt conveyor. The XRF measurements resulted in a MgO content of 3.6 % for the limestone and 10.5 % for dolomite compared to 4.5 % for the entire batch. If the unclassified content is included in the limestone fraction instead of the return flow, the MgO content does not change significantly. The averaged analysis results of the laser measurements result with practically the same average value for the two classes in contents of 3.1 % and 13.3 %. The somewhat wider spread of the values can in turn be attributed to the inhomogeneities of the samples.

Summing up, it can be said that with production-oriented conditions (3 m/s belt speed, untreated production samples), effective single particle sorting based on laser direct analysis was achieved. With a discharge of only a good eighth of the material, the MgO content of the useful rock could be lowered significantly by one fifth from 4.5 % to 3.6 %. In further tests with other batches and sorting thresholds MgO-depletions were also realized, for example from 5.1 % to 3.7 %.

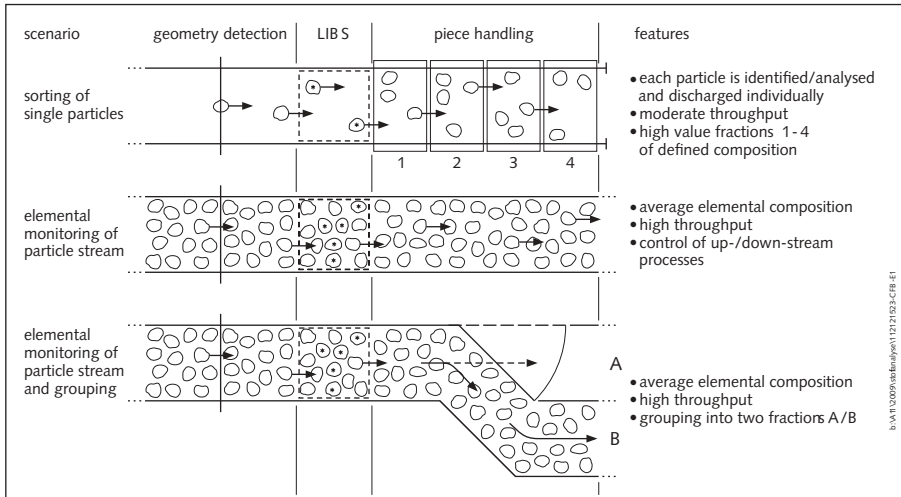
### 5 Potential applications and conclusions

With laser direct analysis, online measurement data on the material composition of the extracted raw material can be obtained directly. The presented technology provides a direct sorting criterion for mineral processing. In combination with processes for singling, detecting and discharging particles, an efficiently operating sorting system could be realized.

The online analysis can be used in various configurations in raw material processing. Fig. 9 shows the different approaches. Besides the previously described single particle sorting, both straight characterization of the material stream as well as grouping of the stream on basis of temporally averaged analysis results are possible.



8 Mean magnesium contents of the sorted fractions for limestone and dolomite



9 Application scenarios for laser direct analysis. The measured objects travel from left to right on a belt conveyor. Top: Single particle sorting, Centre: Characterization of material streams, Bottom: Characterization of material streams and grouping

Also in single particle sorting, laser analysis can be used additionally for sorting decision for individual particles also for monitoring the average composition of the fractions obtained. Thanks to a continuous automatic determination of the decisions criteria for the sorting, a raw material stream with a constant composition and high yield can be obtained. Thanks to the production of particularly high-grade products and a low loss of value material, a significant value increase in mineral processing and therefore economic use of the system is possible after only a short time of use. As the measurement method does not entail any intervention in the process flow and does not use any ionizing radiation, it can be easily integrated in existing plants.

With the help of the new sorting method, problems can be resolved for which there has so far been no efficiently functioning process. As a result, previously unexploited deposits, but also previously unworkable parts of deposits already

being mined or quarried can be considered for exploitation.

By an adaption of the spectroscopic measurement method, laser direct analysis can be adapted to meet a wide range of requirements. Thanks to this flexibility of the process, it is not only suitable for limestone processing, but also for processing a wide range of other ores and industrial minerals. As this process is a dry processing method, it is also suitable for use in areas in which water is not or insufficiently available as a process medium. Accordingly, sorting applications can be realized in (semi-)arid regions as well as regions with permafrost soil [6].

**Literature**

- [1] Wotruba, H.: Stand der Technik der sensorgestützten Sortierung, Aufbereitungstechnisches Seminar 2008, Sortieren in der Mineral- und Sekundärrohstoffindustrie, Leoben 2008
- [2] Einzelkornanalyse zur Mineralientrennung mit hohem Massendurchsatz bei der Gewinnung von Primärrohstoffen (EIGER), [http://www.vdivde-it.de/innonet/projekte/in\\_pp095\\_eiger.pdf](http://www.vdivde-it.de/innonet/projekte/in_pp095_eiger.pdf)
- [3] Lasertechnik für die Fertigung, Hrsg. R. Poprawe, Springer, 2005, Kapitel 18.6, S. 429-442
- [4] R. Noll, V. Sturm, Ü. Aydin, D. Eilers, C. Gehlen, M. Höhne, A. Lamott, J. Makowe, J. Vrengor, LIBS – from research to industry, new frontiers for process control, Spectrochimica Acta Part B 63(2008)1159-1166
- [5] Ü. Aydin, R. Noll, J. Makowe, Automatic sorting of aluminium alloys by fast LIBS identification, 7th Int. Workshop Progress in Analytica Chemistry in the Steel and Metal Industries, ed. J. Angeli, Glückauf GmbH, Essen, 2006, 309-314
- [6] Wotruba, H.: Sensor Sorting Technology- is the Minerals Industry Missing a Chance? Plenary lecture. XXIII International Mineral Processing Congress, Istanbul, 2006