Fraunhofer

IWS Dresden

FRAUNHOFER-INSTITUT FÜR WERKSTOFF- UND STRAHLTECHNIK IWS

imanto imaging tools

imanto® *TOOLS, SOFTWARE & APPLICATIONS*

Non-destructive screening, 100 % inspection and characterization
by hyperspectral imaging

OVERVIEW

Nowadays a 100 percent quality control option is the essential requirement for industrial products. Furthermore, modern inspection tools must meet many demands with regard to flexibility, acquisition time, data evaluation, process integration, and process interaction. A dedicated spectroscopic technology, which meets all the mentioned criteria, is the hyperspectral imaging (HSI) technology. With **imanto®** the Fraunhofer IWS offers a platform including powerful tools and solutions to perform optical imaging spectroscopy for different requirements.

TECHNOLOGY

Based upon early multispectral imagers, the ongoing technological development allows the usage of larger sensor sizes. The new sensors offer several hundred spectral bands for a few hundred spatial positions at one time. Furthermore the HSI technology has no moving optical parts, a fact which increases the system's robustness.
Standard HSI systems are available for the ultraviolet (UV), visual spectral range (VIS) and for the near infrared range (NIR – sometimes also called short-wave infrared: SWIR). The available information includes:

- UV spectral range *250 – 400 nm*
  - fluorescence properties
  - electronic state properties
  - surface morphology
  - thin film properties
- VIS spectral range *400 - 1000 nm*
  - optical properties: color, absorption, scattering
  - fluorescence properties
  - electronic states
  - surface morphology
  - thin film properties
- NIR spectral range *1000 - 2500 nm*
  - chemical features, sample composition
  - contaminations and defects
  - surface morphology
  - thin film properties

Also a combination of different spectral ranges to gather combined information classes can be realized.

DATA HANDLING

A challenging task for hyperspectral imaging is the data handling due to the high acquisition rates of up to 1 kHz. **imanto®** *pro* has been developed to provide a fast calculating software. The software package can be used for stand-alone applications as well as for real-time tasks. Additional algorithms for data mining and statistical analysis can be further integrated just according to your demands.

The imanto® platform offers:

- non-destructive product testing and inspection, process monitoring and materials characteristics analysis
- lighting tools:
  options for reflective (glancing) substrates and special adaptions
- software package:
  data acquisition, evaluation and multivariate statistics, real-time option
- VIS- and NIR-HSI microscopy
- customer-driven solutions

- feasibility studies
- process monitoring development
- industrial adaptions
- data mining and statistical analysis

YOUR ADVANTAGE

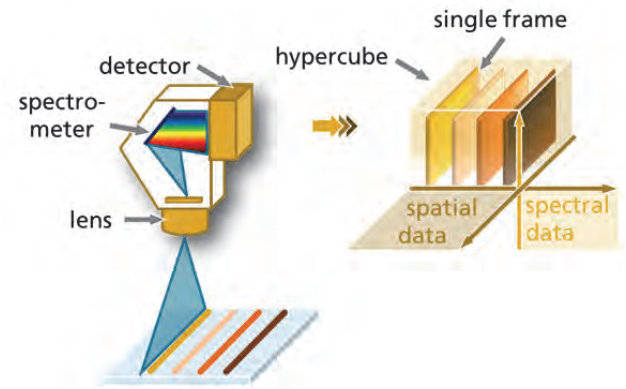
The scientists of the Fraunhofer IWS help to analyze the necessary background for the implementation of the HSI technology and to adapt the system to process control or production lines. Beside the hardware integration all further steps can be supported by Fraunhofer IWS:

- feasibility studies
- software adaption
- development and implementation of data processing algorithms
- support for industrial operation

In fact, a broad portfolio of services can be tailored to the given specifications. Hardware tools for lighting, microscopy and further accessory can be additionally developed and customized to the special needs.

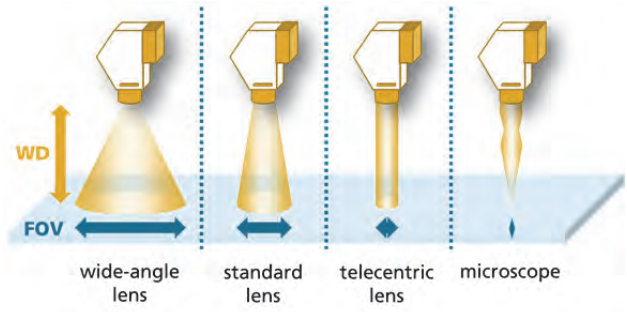
HOW IT WORKS

Hyperspectral imaging works as a line scanning system, but every spatial point will be split additionally into its spectral components. The resulting two-dimensional image is subsequently mapped on focal plane array detector. For recording a complete sample, either the HSI system or the sample itself must be moved. The collected data are summarized in a data structure called "hypercube".



Scheme of the spectral data acquisition process of a HSI system

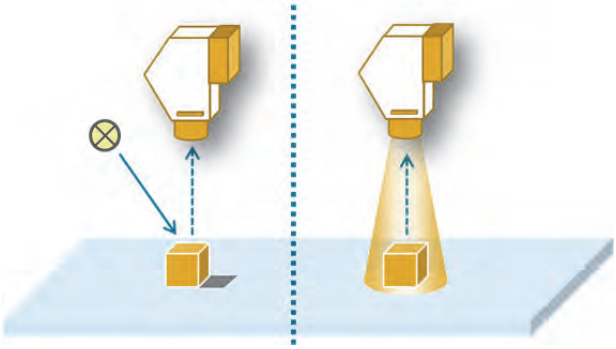
The working width of a hyperspectral imaging system mainly depends on the focal length of the used lens and the working distance (WD). Thus the field of view (FOV) of a few millimeters (microscope optics) up to several meters and more can be realized.



Different optic configurations for HSI systems

In HSI measurements the spectral and spatial resolutions are primarily influenced by the detector's pixel number. The spatial resolution is further determined by working width, scanning speed of the HSI system and sample velocity. This means, that hyperspectral data may have two different spatial coordinates in dependence of the acquisition parameters.

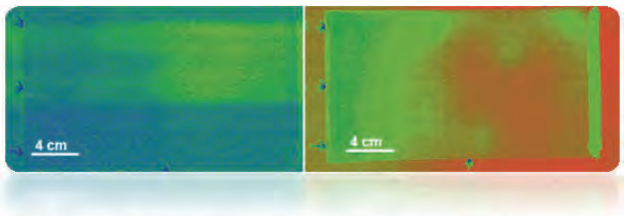
A crucial point in hyperspectral image acquisition is the choice of an appropriate lighting. The lighting is decisive for a successful measurement. A spatial homogeneous brightness helps to achieve a reliable data set and to reduce efforts in data evaluation.



Lighting in hyperspectral imaging, differences between spot and diffuse lighting

In accordance with the samples morphology and structure, a spot-, line- or diffuse lighting is applied for the measurements. Special cases are transmission or specular reflection setups, which are commonly used with a microscope optic.

Example



Stainless steel substrate with aluminum oxide layer, left: spot lighting: primary beam reflections and the substrate's grain structure are mainly visible, right: diffuse lighting on the same substrate: the Al_2O_3 thin film emerges and can be evaluated subsequently.

Hyperspectral imaging:

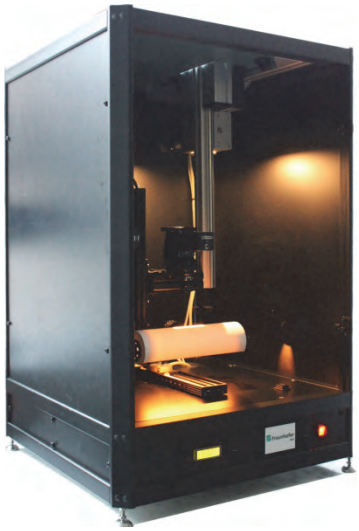
- non-destructive, contact-free spatially resolved spectral measurements
- more than 100 spectral bands
- frame rates up to 1000 fps
- different wavelength and information ranges: UV, VIS, NIR
- various applications due to manifold combination/integration possibilities
- additional information in combination of image interpretation and spectral evaluation

imanto® *obsidian*

Hyperspectral measurements are diversified according to the wide application range for surface and imaging applications. If the application is once established, the benefits of hyperspectral imaging will remain. Successful measurements need profound know-how to achieve optimum results. The **imanto®** platform offers application oriented ready-to-use solutions with respect to hardware and software.

TABLETOP SYSTEM

Our tabletop systems are easy to use and ready for future enhancements of the measurement platform. By default, a x-stage is adapted to the system. In addition, the appropriate **imanto®** *lighting* option and the **imanto®** *pro* software package offer a complete hyperspectral imaging solution for the first steps in hyperspectral imaging spectroscopy.



imanto® *obsidian tabletop system*

Beside the common versions, the system platform can also be easily adapted and configured to your specific interests.

imanto® *obsidian* options:

- small conveyor belt
- cross-table (x, y)
- microscopy option with high precision x-y stage for highest spatial resolution
- fiber-coupled lighting
- vacuum table

LARGE-SCALE AND PROCESS-LINE SETUPS

Large-scale and process-line setups are customized according to your needs. However the modular system of the **imanto®** platform fulfills the requirements of an easily configurable system setup. All boundary conditions must be considered for the integration of a reliable measurement system. We provide assistance for all steps in process line integration:

- task analysis & feasibility studies
- HSI system and software adaption
- data evaluation and development of data analysis models
- process line integration (i. e. Beckhoff systems)

HSI monitoring systems can be integrated into existing as well as into upcoming process lines.

Rugged 3-axis motorized large-scale setup

imanto® *obsidian*

- configurable with **imanto®** *lighting* and **imanto®** *pro* components
- tabletop system
  - durable construction components
  - flexible sample stages, up to 30 cm travel range
  - motorized z-axis (height)
- large-scale and process line setup
  - 3-axis motorization, camera movement
  - dedicated control cabinets
  - process line integration (i.e. to conveyor belt)
- accessory
  - customized measuring tables (vacuum option) and HSI system take-up

imanto® *pro*

For an easily and efficiently use of the broad potential of HSI, Fraunhofer IWS developed a software package for scientific and industrial use. In stand-alone tasks the spectroscopic characteristics come to the fore and additional efforts must be done for data exploration and analysis.
The **imanto®** *pro* software package offers the full acquisition and measurement control. All spectroscopic measurement setups are supported – from emission to transmission and several reflection setups. In combination with the possibilities of the time-resolved ("staring imager") and spatial-resolved measurement modes, a very flexible software solution for all essential HSI-data processing steps is provided.

Beyond the pure data acqusition, all needed functions for data analysis and manipulation are given. Statistical, chemometric models for advanced data treatment and large data sets can also be integrated. **imanto®** *pro* is highly scalable on multiple processor cores and uses accelarated libraries for highspeed calculations.
This feature also enables the real-time application of the software algorithms to process and quality control tasks. For this purpose, the software is able to connect to industrial controls and the output data can be customized to appropriate requirements.

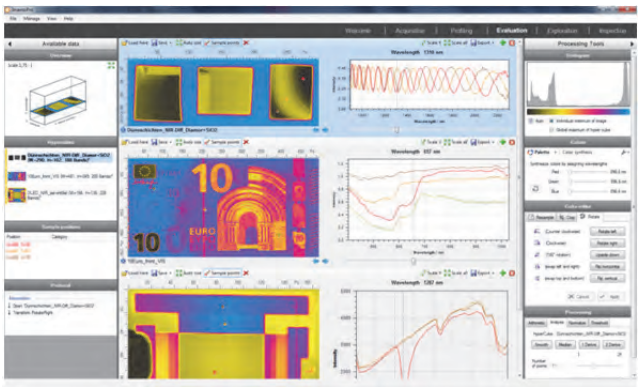
GRAPHICAL USER INTERFACE

- simple, intuitive interface
- receipt concept
- multi-data screen
- interactive data evaluation

imanto® *pro* demands

- Intel® Core i5 processor or better; quad-core processor recommended
- RAM 4 GB+
- monitor with resolution of 1366 x 768 pixel at minimum
- Microsoft™ Windows 7
- Microsoft™ .NET Framework 4.5

- optional: CameraLink interface
- optional: real-time interface



imanto® *pro* user interface

INTEROPERABILITY

- any multi- and hyperspectral camera can be integrated
- data format:
  - ENVI, generic HSI.JPG
- spectra and picture export

DATA PRETREATMENT

- offset correction (dark image)
- background correction (bright image)
- fault pixel correction

SUPPORTED MEASUREMENT SETUPS

- supported movement systems:
  - x-stage, cross-stage, conveyor belt
- supported measurement modes:
  - diffuse and specular reflection, transmission, emission
- macroscopic and microscopic measurements
- time-resolved measurements (staring imager set-up)
- continuous measurements

SPECIAL FEATURES

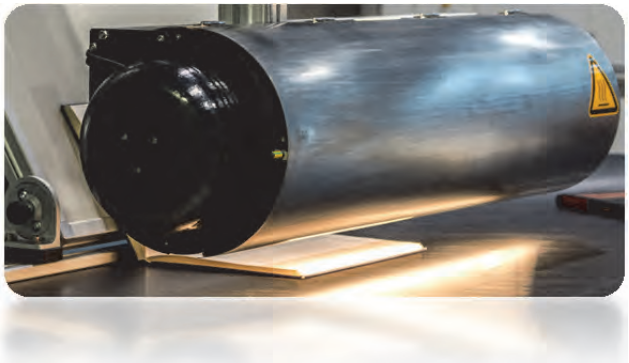
- use of chemometric models, such as
  - SVM, PCA, LDA, QDA, cluster analysis
- integration of third-party modules:
  - CAMO® classification engine, Intel® MKL, Extreme Optimization™
- *on-line* data processing

imanto® *lighting*

For several imaging and spectral applications a broadband lighting is necessary for the acquisition of full information depth. The halogen lighting covers the full spectral range from visual up to the near infrared (VNIR, SWIR) range.

FLEXIBLE LIGHTING SOLUTION

Beside common line lights and spot lights, which are also available for **imanto®** *obsidian* setups, many tasks require a homogeneous lighting. The **imanto®** *lighting* solutions provide a diffuse lighting like a standard integration sphere with optical access for the HSI-system. A flexible setup allows the adaption to almost every working width. High quality components enable a long-term operation.



imanto® *lighting (80 cm working width), for HSI-digitalization of cultural-historical valuable writings.*

All lighting solutions are ready-to-use and will be combined with specially designed and stabilized power sources. For the latter, also power sources with constant output for process tasks are available as well as adjustable power sources for research tasks.

Depending on the size, the spheres are either fully made of optical PTFE or internally coated with optical PTFE. A high reflection of ≥ 98 % for the whole UV/VIS and near infrared spectral range enables the **imanto®** *lighting* device to easily perform reliable measurements. The designed working width of up to 80 cm shows a homogeneity of illumination of > 95 percent.

imanto® *lighting in a small configuration (24 cm working width; integrated into a* **imanto®** *obsidian system)*

MEASURE REFLECTING SUBSTRATES

Hyperspectral measurements of high specular reflecting materials such as metal substrates and others require a very homogeneous lighting for a high data quality for evaluation. Otherwise the reflection intensity superimposes the spectral information from the UV/VIS- and NIR-range by overexposure of the detector.

imanto® *lighting*

▪ spectral range	250 – 2500 nm
▪ material	optical PTFE ≥ 98 % reflection
▪ homogeneity	> 95 %
▪ working width	up to 80 cm
▪ exit slit width	1 – 5 cm / adjustable
▪ unit power	40 – 300 W
▪ # sources	2 - 6 per unit

imanto® *microscopy*

Since the spatial resolution of standard lens combinations for hyperspectral imaging systems is limited, Fraunhofer IWS offers a solution for the combination of HSI and microscopy for the UV/VIS as well as for the near infrared spectral range. Thus the microscope hardware becomes very flexible: filters and polarizers can be integrated into the beam path; the eye-piece can be used in alteration with the HSI system without any hardware change.

HYPERSPECTRAL MICROSCOPY

Hyperspectral microscopy is a powerful tool to analyze small sample structures for biological and material science tasks. The enhancement of the near infrared spectral range opens up totally new possibilities for sample characterization due to the use of chemical information of the samples. By using a high-precision motorized cross table, the sample analysis can be further automatized. The spatial HSI resolving capacity is now raised up to 200 nanometers in visual range and up to 2 microns in near infrared range.

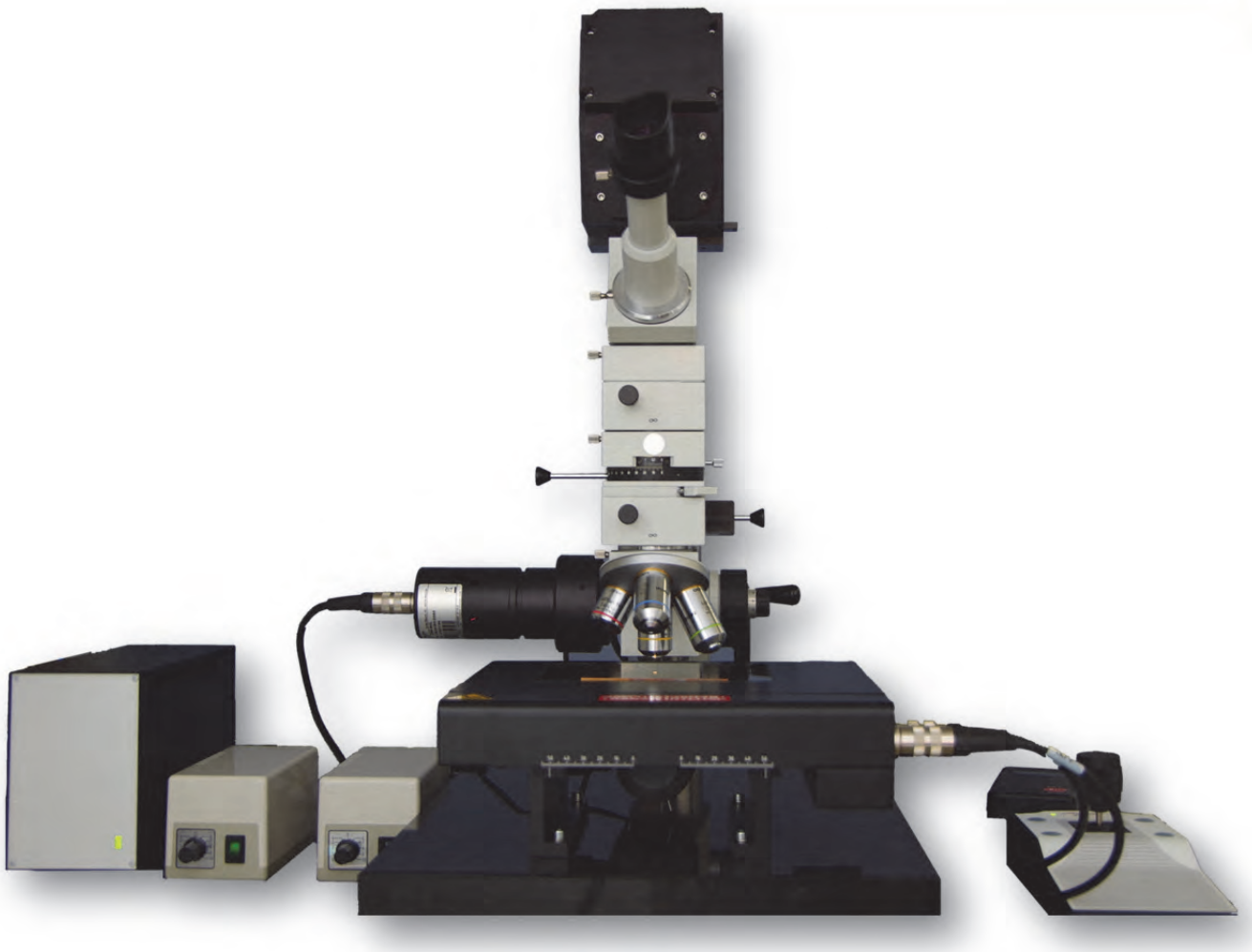
THIN FILM ANALYSIS

An extraordinary advantage of the combination of microscope and hyperspectral imaging system is the specular reflectance setup provided by the microscope's beam path. This feature allows thin film analyses (e.g. film thickness) of nearly any kind in a very high spatial resolution. Based on optical calculations, the analysis can be applied for the entire surface in a very short time. Beside this, the chemical and/ or UV/VIS characterization of samples can be also done as usual.

imanto® *microscopy*

- NIR and UV/VIS imaging in one system
- spatial resolving capacity:
  < 200 nm UV/VIS; < 2 µm NIR
- specular reflectance and transmission measurements
- motorized 3-axis workbench
- fourfold nosepiece
- use of standard microscope lenses

- optional: integration of filters and polarizers



imanto
imaging tools

imanto® *applications*

THIN FILM INSPECTION

The monitoring of thin film parameters can be a crucial point in a coating process. In contrast to cross-section SEM or ellipsometry hyperspectral imaging allows the *in-line* or *at-line* monitoring of the entire thin film.

The properties of thin film samples are calculated by using the concept of beam propagation in layered media. In dependence of the nature of the thin film either the UV/VIS and/or the NIR spectral range is used for data evaluation.
For highest acquisition rates and fast *in-line* measurements the data analysis can be accelerated and combined with individual multivariate, mathematic-statistical algorithms. Multivariate data analysis can also obtain and control the process parameters. Therefore the statistical models must be trained by single parameters measurements.

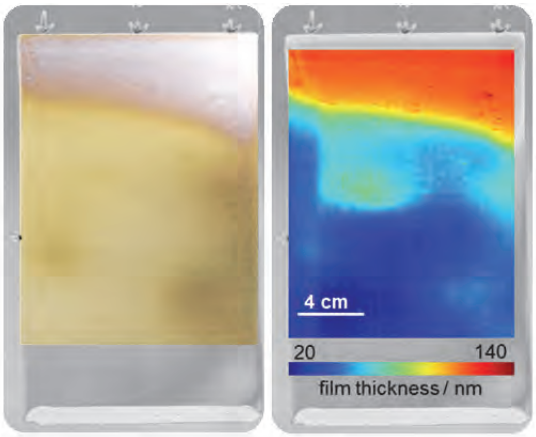
Hyperspectral imaging setups for thin film inspection can be realized with the **imanto®** *obsidian* hardware or **imanto®** *microscopy* combination.

imanto® thin film analysis

- spatial resolved parameters
  - thin film thickness (nm up to µm)
  - sheet resistance (only conductive materials)
  - refractive index (*n*, *k*)
  - failures, defects
  - quality parameter distributions
- substrate materials
  - bulk metals, metal foils
  - Si-wafer, semiconducting materials
  - polymer webs
  - glass
- thin film materials
  - inorganic: (conductive) oxides, nitrides, carbides etc.
  - organic: dyes, oils, fat etc.
  - polymers and composites
  - ultra-thin metal coatings

Film thickness inspection

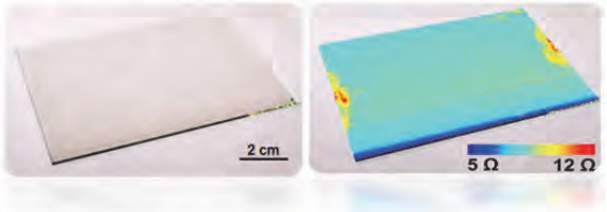
The thin film thickness can be calculated using adequate dispersion models for the substrate and thin film (e. g. CAUCHY model).



Al_2O_3 thin film on steel substrate; left: visual image, right: film thickness image

Sheet resistance measurements

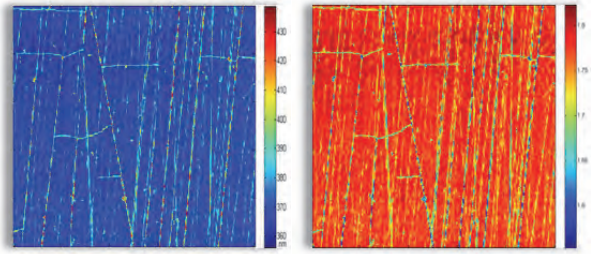
The acquired data can be further analyzed with respect to sheet resistance or conductivity of the film by the application of the DRUDE-model.



Sheet resistance image of indium tin oxide (ITO) on glass; left: visual image, right: sheet resistance distribution

Refractive index analysis

Coupled with the film thickness, the distribution of refractive index parameters can be determined as well.



Doped ZnO on ETFE-foil; left: film thickness image; right: refractive index (n) image

imanto® *applications*

SURFACE IMAGING

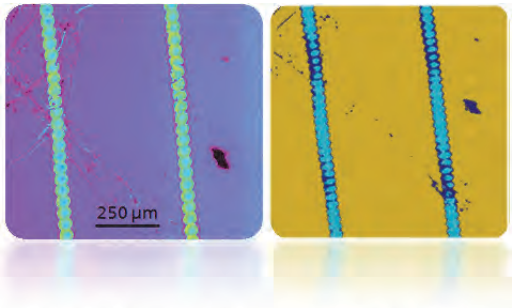
Surface analyses are commonly found in process and quality control application tasks. The ability of detecting hidden features helps to evaluate the product or process step. In combination with an automated statistical analysis a defined yes/no decision can be done. For surface imaging applications hyperspectral imaging offers in UV/VIS and in NIR spectral range appropriate information.

imanto® surface imaging

- contamination screening
  - greasy contaminations
  - impurities, foreign matter
- emission measurements
  - plated metals
- surface quality
  - cracks, holes, gaps
  - roughness

Laser scribing

For organic electronics the defined laser ablation is important for structuring OPV components and others. HSI offers significant potential to analyze the homogeneity and penetration depth of the scribes and the integrity of the layer below.

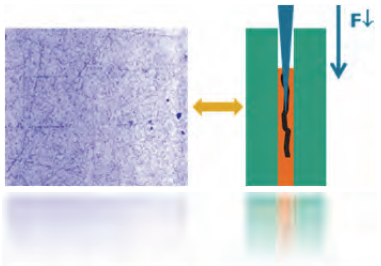


Laser scribed OPV device, left: HSI image (590 nm), right: classified image (yellow – active layer, blue – ITO, dark blue – damaged base layer)

Adhesive strength

Full surface imaging is mandatory for control of component parts for bonding. IWS scientists developed a method for the prediction of the adhesive strength by HSI inspection of the surfaces to be bonded.

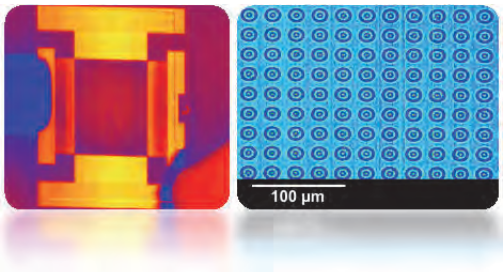
Significant advantages are non-destructive testing, fast measurement and prior knowledge in respect to the well-known wedge test.



SiO_2 coated Ti-alloy, a smart data evaluation leads to corresponding wedge test results within 1 minute

COMPONENT TESTING

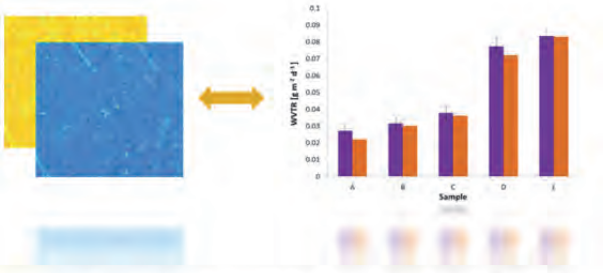
The bandwidth of possibilities for component testing ranges from active layer control to surveillance of uniformity of printed microstructures. It is possible to define particular quality parameters for every task – just right out of the HSI data set.



Left: NIR-image (1302 nm) of an experimental OLED-device, right: control of printed "donut" polymer structures

WVTR inspection

The use of all information of the acquired spectra and their distribution offers the possibility to estimate the water vaper transmission rate (WVTR) for barrier webs. The measurement time decreases by several orders of magnitude.



Barrier foils, left: evaluated HSI images, right: predicted WVTR by HSI (purple) in comparison to reference measurements (HiBarSens®, orange)

imanto® *applications*

SORTING

The main tasks for HSI sorting applications are established in the food industry and polymer sorting. Especially the NIR spectral range offers access to chemical information of the materials. The real-time ability of the data analysis is important for these applications. Chemometric data analysis algorithms are implemented for this task, in certain cases simpler evaluations, based on spectral intensity levels, can also be used. The extracted information can be subsequently transferred to sorting machines or other process line machines.

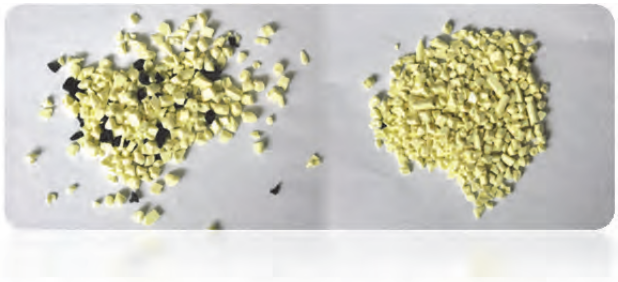
imanto® sorting, recognition and classification:

- target parameter:
  - material type
  - aging, imperfections (i. e. food)
  - purity and foreign matter
- all kind of powders, regrinds, pellets and granulates
- polymers:
  - household: PE, PP etc.
  - technical: PA_x, PC, ABS etc.
- food:
  - crop: barley, wheat, rye etc.
  - fruit and vegetables: apples, nuts, peas etc.
  - meat
- pharmaceutical and chemical products
  - pills, powders and granulates
  - minerals

Polymers

A sorting process based on VIS hyperspectral imaging is able to evaluate the color, but in most cases this information is not significant enough for a full differentiation of multiple polymer mixtures. The NIR spectral range provides more information and offers the solution for these tasks.

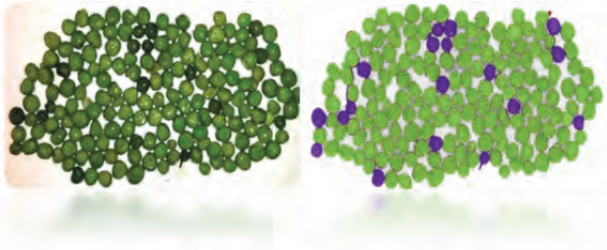
At Fraunhofer IWS the NIR based recognition is simultaneously shown for 12 colored polymers. For black polymers commonly up to 4 black polymers can be identified at a time.



Left: polymer fraction with POM (yellow) and TPE contamination (black), right: sorted POM fraction

Solanum in pea crop

Modern agriculture requires technologies to reduce impacts of foreign weeds before processing, due to the reduction of herbicides and plant protection products and the increasing organic-food industry. HSI is well suitable for such recognition tasks.

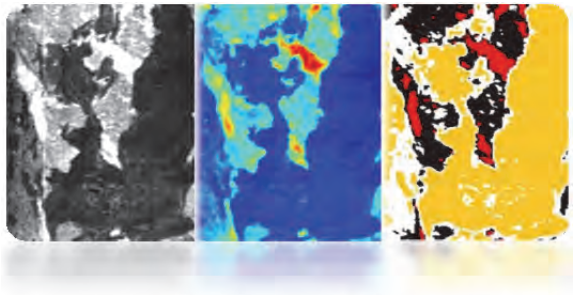


Left: visual image of solanum in pea crop, right: classified HSI image, solanum fruits are marked in purple

The recognition of solanum in pea crop is not capable by standard machine vision technology.

Mining exploration

The rating of the mineral content of drill cores and dismantled material is essential for the success of a mining project. Hyperspectral imaging helps to evaluate the mineral content.



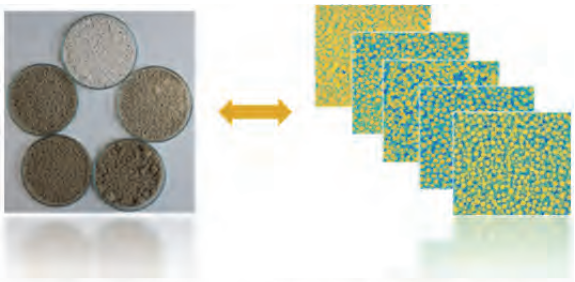
HSI measurement of a drill core, left: visual grey scale image, middle: NIR image (1490 nm) and right: classification and assignment to different types of minerals

imanto® *applications*

RECOGNITION AND CLASSIFICATION

A further sorting related task is the recognition and classification of materials – for example to inspect dedicated substance content. These tasks are not mandatorily coupled to a sorting process. To achieve a defined result, the spectral data will be usually processed by mathematical-statistical algorithms. Fraunhofer IWS will provide any assistance for a tailored solution for your task. In combination with the **imanto®** *pro* software an easy-to-use user interface and software module for all steps of recognition and classification is available.

Batch process control



Granulate of different process states, left: visual image, right: processed HSI images

In batch processes, HSI is able to determine the process state and ending point by using spectral and spatial data evaluation in a combined algorithm. Furthermore the results offer the possibility to influence the batch process for optimal results.

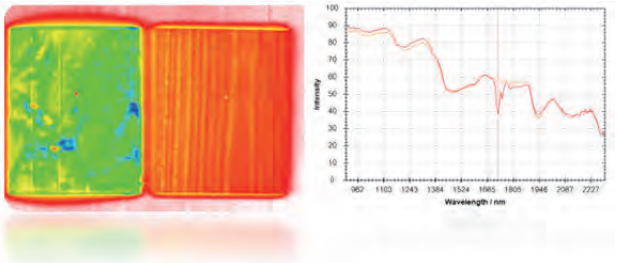
Powder purity

The quality and purity control of powder mixtures is an important task in many chemical processes. Beside crystalline and amorphous powders also metal powders for additive manufacturing processes can be assessed.

Crystalline powder of metal-organic frameworks, left: visual image, right: classified HSI image

Wood impregnation

In the past decades wood was often impregnated with toxic substances such as LINDAN, PCP or DDT. To avoid skin-contact a HSI-based screening of roof frames prior to restauration provides information about possible toxic substances and their spatial distribution.



Left: with LINDAN impregnated and untreated wood, right: HSI spectra; the high intensity levels of the impregnated wood (green, blue) correspond directly to the absorption peak in the shown spectrum

Genuineness of documents

Hyperspectral measurements are, due to their spectral imaging, perfectly suited for verification of the authenticity of documents. Multiple hidden features in the documents can be perfectly visualized. In combination with pattern recognition, multiple features can be analyzed. VIS and NIR spectral ranges are applicable in dependence of the document type.
Examples are banknotes and counterfeit recognition as well as restorations of ancient documents and their clear assignment to an author or artist.

Ancient document with stubborn stains, HSI enables librarians to reconstruct the original text (small insertions)

imanto
imaging tools

Embedded in grass, the "IWS" writing was made of synthetic turf and visualized by hyperspectral imaging

imanto® brings the information to light.

Spectral analysis
by hyperspectral imaging!

Contact address:

Fraunhofer IWS Dresden
Winterbergstraße 28
01277 Dresden
Germany
www.iws.fraunhofer.de/imanto

Dr. Philipp Wollmann
Phone: +49 351 83391-3316
Fax: +49 351 83391-3300
philipp.wollmann@iws.fraunhofer.de

Dr. Wulf Grählert
Phone: +49 351 83391-3406
Fax: +49 351 83391-3300
wulf.graehlert@iws.fraunhofer.de

imanto® *obsidian* | **imanto®** *lighting* | **imanto®** *microscopy* | **imanto®** *applications*

Patents pending

imanto
imaging tools