Imaging Spectroscopy for Microelectronics

Designing innovative LED structures with a Hyperspectral Imaging Microscope System

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Imaging spectroscopy has proved its worth in the acquisition of geological parameters from the air or by satellite in order, for example, to answer environment-related questions such as relating to the water quality of lakes. On a microscopic scale, the method can be applied to good advantage for multi-channel spectral analysis of light-emitting semiconductors in the design of innovative LED structures. For this purpose, XenICs has collaborated with the University of Twente in the development of a hyperspectral imaging microscope system (HIMS), which allows detailed examinations in the visible and near infrared range with high precision. Early measurement results on LED structures, achieved through the new imaging device, and an evaluation of the hyperspectral scanner images using the X-Cube software clearly show the viability of this method for microelectronic applications.

Light Emitting Semiconductor Structures

Light emitting semiconductor structures have been used for a long time in the form of LEDs which, due to their increasing efficiencies, have made substantial inroads into illumination technology, competing with traditional lighting systems as well as enabling innovative illumination concepts. Despite their obvious maturity they still have tremendous potential for further development. For example, at Twente University, the faculty for Electrical engineering and the MESA$^+$ Institute for Nanotechnology have jointly investigated the impact of electrical fields on lateral LED structures as shown in Figure 1.

In this structure, a gate electrode of poly-silicon has been placed above the active, light emitting region. Operating the diode with constant current and a negative gate bias will cause it to shine brighter. Additionally, the intensity profile of the radiating surface is significantly changed. Thus, the light emission of an LED can be specifically varied via an MOS gate. This enables novel applications in the illumination, measurement and automation technologies. To understand the basic mechanism of this, the structure must be modeled and compared with the experimental results. The more precise and meaningful the results of this comparison are, the more accurate the modeling will be.

Often the indication of mere intensity data across the various surface elements is not sufficient: intensity must be complemented by the spectral distribution at the locations considered. For a solution of this problem, the methods of spectral imaging on a micrometer scale are required.

Hyperspectral Analysis

Basically, imaging spectroscopy, or hyperspectral analysis, is a happy fusion of spectroscopy and imaging processing. It is an outgrowth of the demands in the exploration of mineral deposits and it has since proven to be an efficient exploration tool from the air and by satellite in the most diverse tasks, such as water quality analysis of Bavarian lakes, the ecology

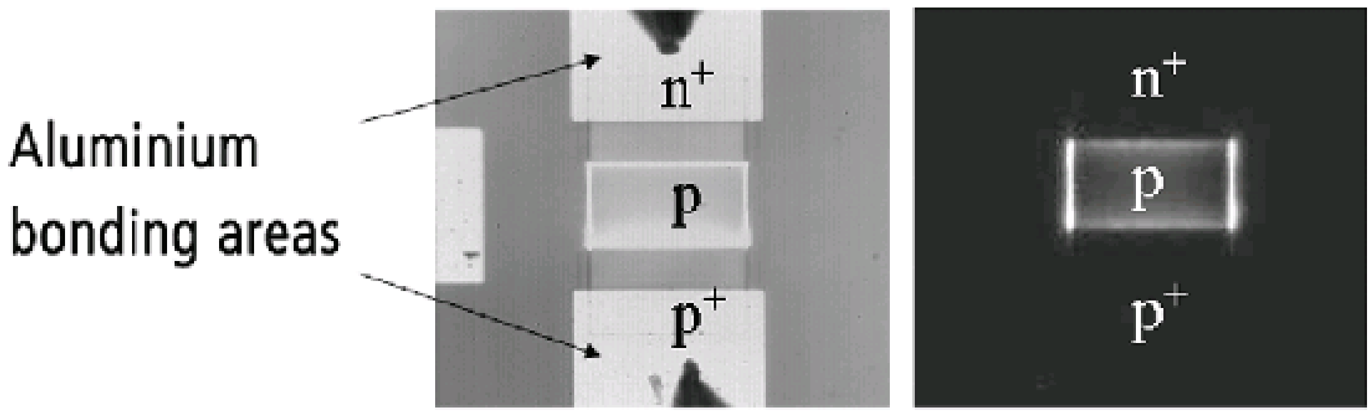

Figure 1: Infrared image of an LED at 5mA forward current,
a) illuminated from above, at 0.3msec integration time
b) without external illumination, at 0.1sec integration time.

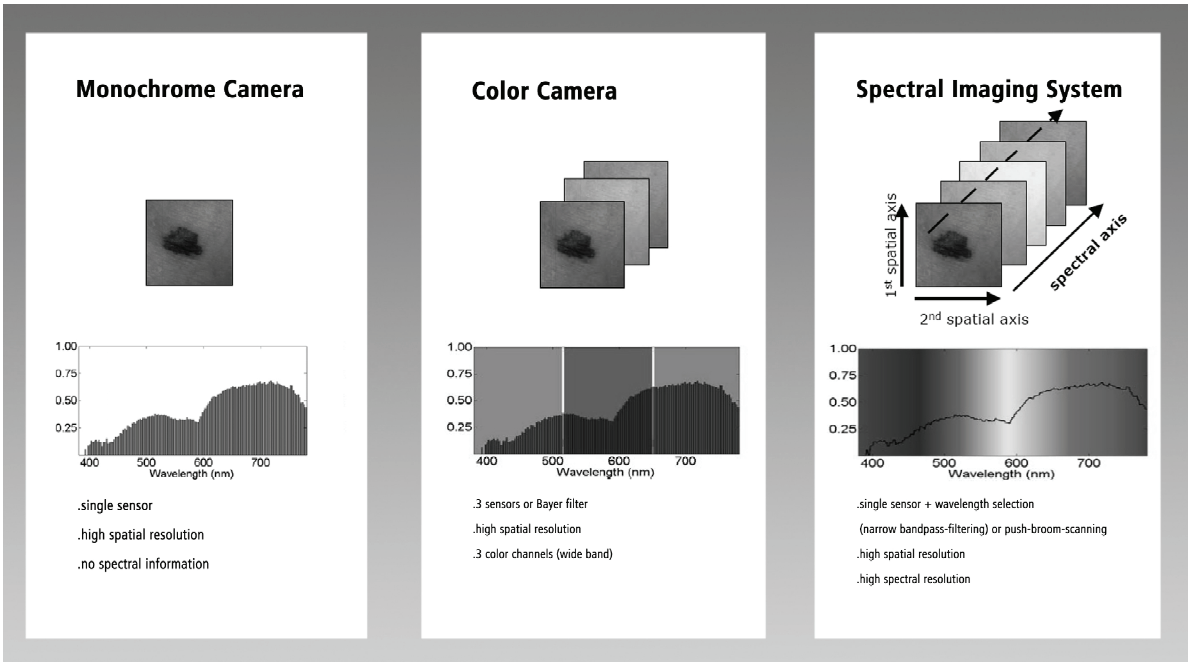

Figure 2: Evolutionary path from monochrome image through multi-spectral color capture to hyperspectral data cube.

of oyster banks in Brittany, France, the measurement of CO_2 emissions from factory chimneys as well as desert formation in the South of Spain.

Imaging spectroscopy can be seen either as an extension of classical image processing or an enhancement of classical spectroscopy. To begin with the former, let's take a look at figure 2. The simplest case is using a black and white camera that captures the grey-scale values of objects - yielding high surface resolution but no spectral information (besides weighing the spectrum by its own spectral sensitivity curve). A color camera, on the other hand, with three image sensors or a sensor with Bayer color filter, will deliver a multi-spectral image with comparably high spatial resolution and three relatively broad-band color channels of red, green and blue, yet with a relatively low spectral resolution.

Finally, a spectral imaging system - it operates with just one sensor and a tunable narrow-band filter placed in the optical path to select a frequency. Alternatively, it functions as a so called push-broom scanner to perform, usually via mechanical feed of test object or spectrometer, a line-based scan. For every pixel in every line, the spectrum is captured and stored.

Both methods use significantly more color channels. This is why they are called hyperspectral: they deliver high spatial resolution and, at the same time, high spectral resolution. The measured data of the X- and Y-coordinates and the radiation components at certain frequencies are located in a three-dimensional data space (cube), as indicated in the upper right of figure 2.

Hyperspectral Microscope

The HIMS hyperspectral microscope was jointly developed by XenICs and Twente University. It is to be used for research work on light emitting semiconductor structures in the infrared (IR) region. Figure 3 shows its essential elements. The microscope's lens evidently is designed to work in the IR. A beam splitter deflects about a third of the emission to a laterally positioned CMOS-camera, which serves as a tool to direct the microscope and select the surface portion of interest on the test object. The IR camera can be positioned on top of this, directly or together with a spectrograph, as Figure 3 indicates.

The IR camera and its InGaAs sensor array are cooled by a

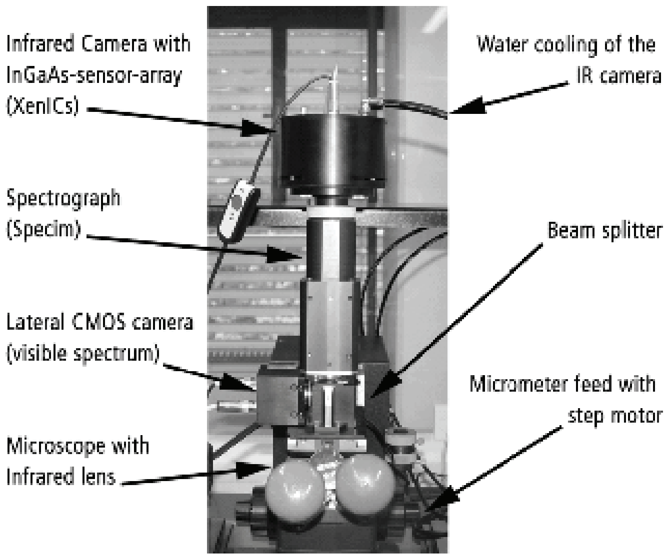

Figure 3: Construction of the hyperspectral microscope at Twente University.

Figure 4: High-resolution, water cooled InGaAs FPA camera of the XenICs XEVA Series.

water-cooled Peltier element. This offers at least two advantages: it works within the camera head without needing a fan. For the user, this lowers the vibration level., and the camera itself is of lighter weight. After all, it is to be moved up to 25mm across the test object by a microfeed with stepping motor to do a line scan.

To be more flexible in its applications, the hyperspectral microscope is constructed as a movable unit. In its base, it carries the PC for the control and evaluation programs, as well as a chiller for the camera's water cooling.

The spectrograph, of Finnish manufacturer Specim, operates in transmission mode - it doesn't require any movable mechanical parts. The dispersion element is a grating with a high permeability of more than 50% and a spectral resolution of 5nm in the NIR area from 900 to 1700 nm. The IR lens of the microscope projects the surface to be measured onto the spectrograph, which performs a spectral dispersion of the impending light and projects the spatial axis as well as the perpendicular spectral axis via a coupling lens onto an NIR surface sensor.

NIR Cameras from XenICs

XenICs is one of the few vendors specializing in NIR image capture and cameras for extremely diverse applications. As a spin-off from IMEC, the leading European research center for microelectronics and nanotechnologies located in Leuven, Belgium, XenICs can draw on a multitude of patented technologies and know-how transfers from its shareholder IMEC.

The software-configurable NIR digital camera (Figure 4) used in the HIMS, with its InGaAs focal plane array covers the standard wavelength area from 900 to 1700nm. Pixel pitch is 30µm at a pixel availability of more than 98 %.

One of the development goals of the hyperspectral micro-

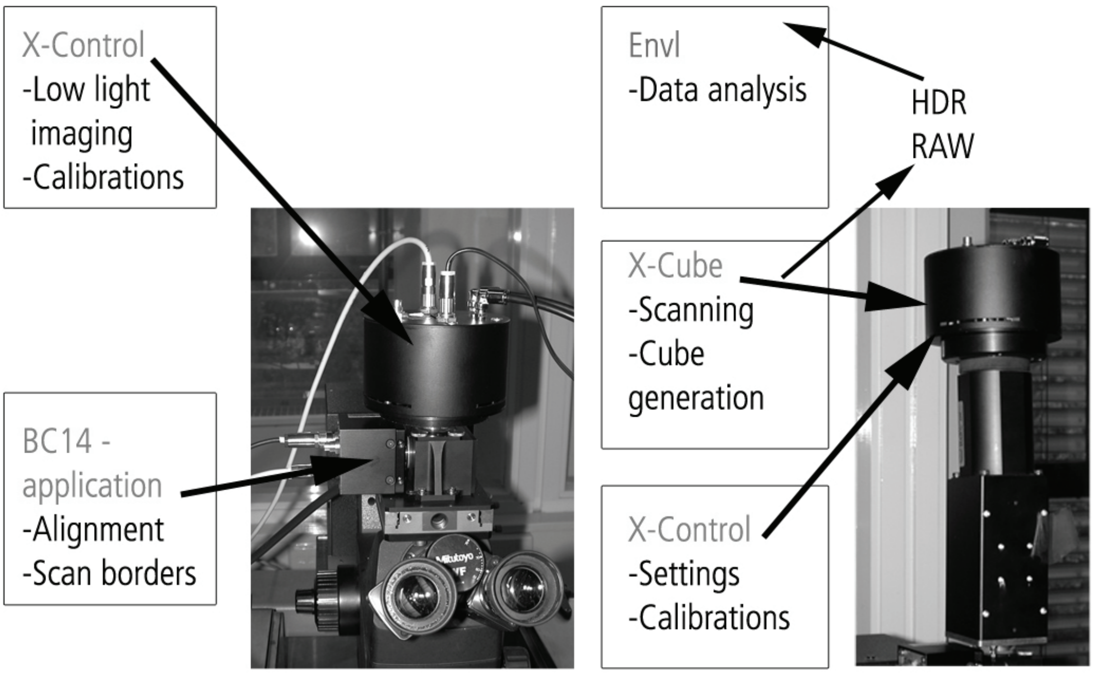

Figure 5: Software environment of the hyperspectral microscope for direct capture and spectral measurement.

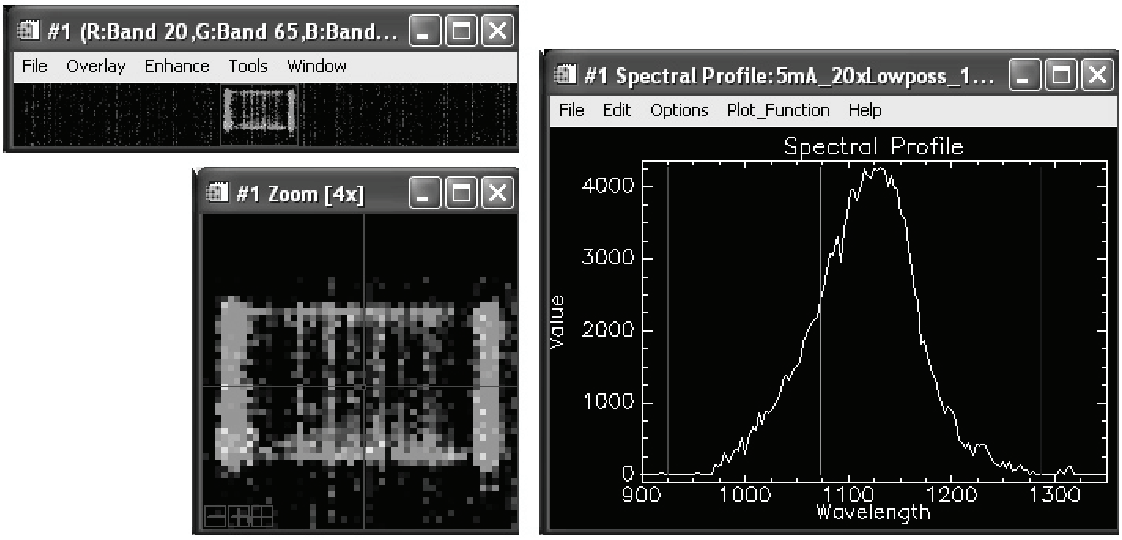

Figure 6: Measurement results for one given point of the LED in Figure 1 (in the crosshairs).

scope was to achieve the same geometric resolution in both X- and Y directions. While pixel pitch determines X-axis resolution, the resolution of the Y axis is tracked by appropriately driving the micro-feed step motor. The camera head communicates with a PC via standard data interface such as USB 2.0 for the control signals, and Cameralink or a parallel LVDS bus for the 14-bit image data. The camera is quickly integrated to different application environments through its standard lens C-mount and spectrometer mount.

A Multitude of Measuring Functions

The hyperspectral microscope is universally applicable in the examination of light emitting semiconductors. Figure 5 shows two different measurement setups for direct surface capture and spectral analysis through the spectrograph. Software support in the case of light emitters is provided by the X-Control graphical user interface, which comes with every camera. X-Control enables direct access to various camera settings, such as integration time or operating temperature. It also contains software tools such as two-point uniformity correction and bad-pixel replacement.

The laterally mounted CMOS camera permits adjusting and selecting the scan area for the hyperspectral examination, which is done by a parameter definition. In the configuration shown on the right this is a very time consuming task. Here, too, X-Control is used for parameter adjustment whereas the X-Cube software tool controls the scan procedure und generates a three-dimensional data set of X-, Y-, and spectral coordinates in *.RAW format. Finally the evaluation is performed within ENVI (Environment for visualizing images), which contains finely tuned and proven programs as well as thousands of options.

First Results of an LED Examination

One of the first captures performed by the hyperspectral microscope is shown in Figure 6: a spectral analysis of the LED structure according to Figure 1 in the ENVI environment. At first in three-channel false-color rendering, followed by four-fold magnification and selection of an appropriate analysis coordinate and finally the spectrum profile. It is clearly visible that a three-channel multi-spectral analysis has only a very marginal meaning.

Outlook

This examination principle is applicable to all materials and structures that fit under a microscope and are in any way marked and identified by specific spectral information. The method's quick and meaningful results can substantially contribute to a shortening of the design procedure of new product introductions and thus accelerate the pace of innovation.

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