Infrared Technologies for 3D Flash Metrology

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Abstract

As 3D Flash manufacturers scale to ever increasing stack heights, the ability to measure individual film layers, zone thickness, thickness profiles or critical dimensions requires extension of the current optics to longer wavelengths. In this paper, we describe efforts to increase the operating wavelength of the Spectroscopic Ellipsometer and Reflectometer to 2.5 µm and beyond with an emphasis on three major areas: (i) Optics architecture changes needed for the spectroscopic ellipsometer and reflectometer, (ii) Detector technology challenges including new architectures for InGaAs, and (iii) Spectrometer architectures which are needed to support IR extensions. Additionally, the engineering challenges associated with thermal management of these InGaAs detectors will be described.

Introduction

Figure 1 is an example 3D flash structure with only 24-bits. The structure shown is that of a contact hole with alternating oxide and tungsten layers. The key challenge is to measure the magnitude of the recess at various locations through the contact. The right side of the figure shows the sensitivity to the bottom recess – virtually all the sensitivity occurs at wavelengths greater than 1000 nm and substantial sensitivity can be achieved at wavelengths up to 2500 nm and beyond.

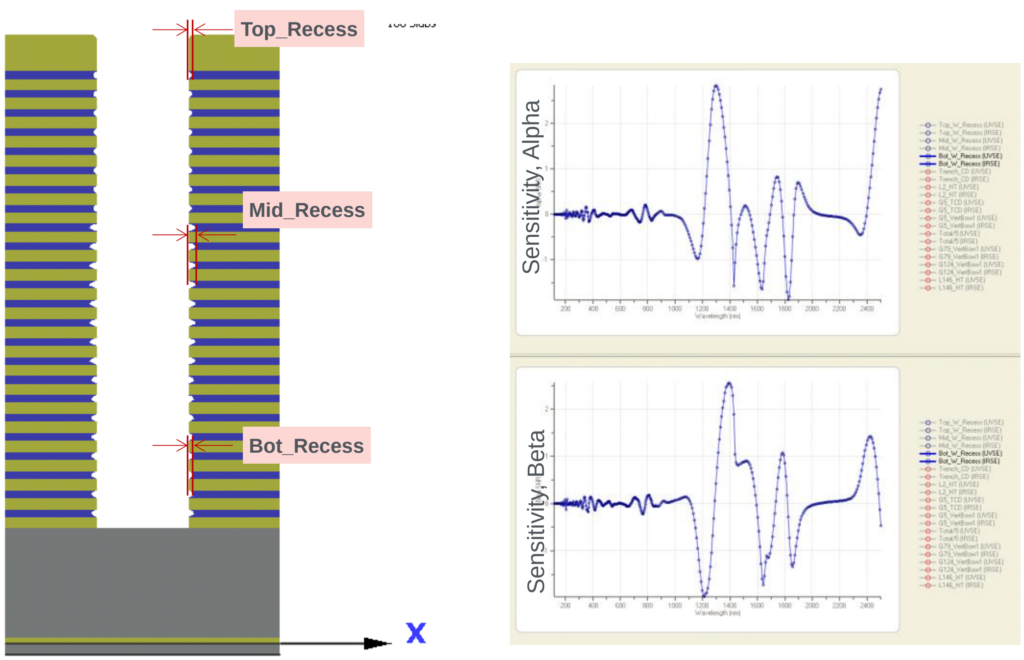


Figure 1: Sensitivity for SE Alpha and Beta vs Wavelength for a 3D Flash structure after the etch – sensitivity to the bottom recess is present almost entirely at wavelengths beyond 1200 nm.

Other examples include thick ACL, OPOP flash structures and scaled versions of the ONON flash structures to 128 bits, all of which benefit from extended IR measurements for both the ellipsometer and reflectometer optics.

New Innovations for extended IR technology: In this paper, we will describe our technical approach as it pertains to three major areas for technology evolution, Spectrometer Design, Detector Technology and Optical architecture.

Novel Spectrometer Designs

The existing spectrometer system measures the UV-Vis spectrum in the 190-900 nm wavelength range using a grating spectrometer. The IRSE spectrum in the 900-1650 nm range is realized by inserting a moving mirror in the main beam path. The data collection for the two spectrometers is serial which results in reduced MAM. This is shown in Fig. 2a. The proposed extended IR spectrometer design uses a novel cascaded design that efficiently collects the IR light in the 0^{th} diffracted order while allowing the UV light to be detected in the -1 order of the first diffraction grating [Ref. 2]. This enables parallel data acquisition improving MAM time significantly. The architecture of the spectrometer is shown in Fig. 2b.

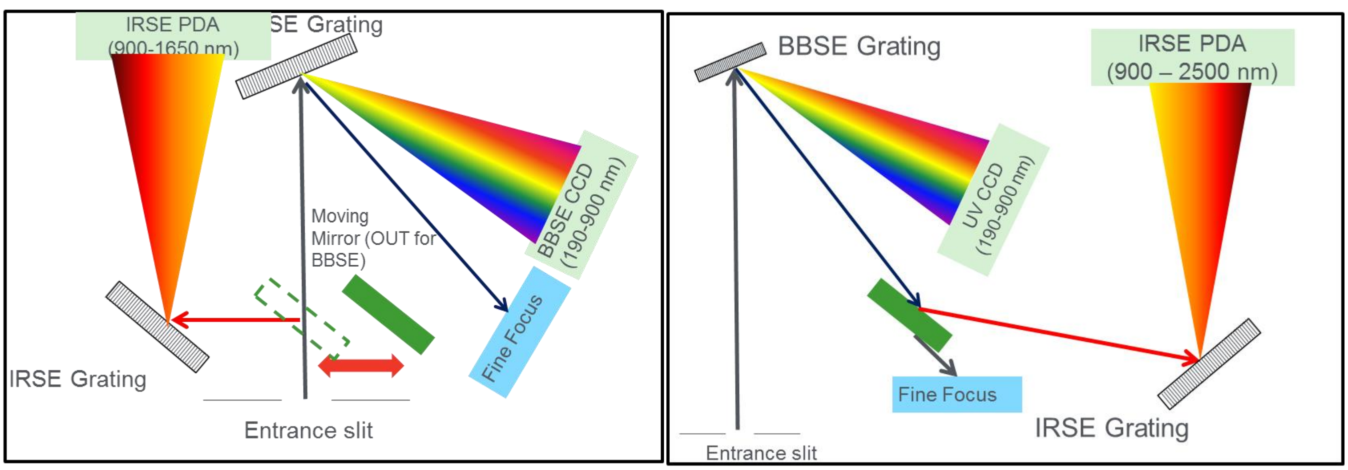


Figure 2: Spectrometer Architecture for a) current serial BBSE and IRSE spectrometer configuration, b)simultaneous broadband detection in the 190-2500 nm spectral range. Light reaches the CCD, PDA and Focus sensors simultaneously and gives the fastest measurement time. The spectral content of each beam is optimized in each of the specific wavelength ranges.

Hybrid InGaAs Detector Technology: Detection challenges in the IR

Figure 3 shows the sensitivity and quantum efficiency of several candidate InGaAs detectors. The challenge is to cover the entire wavelength range from 900-2500 nm.

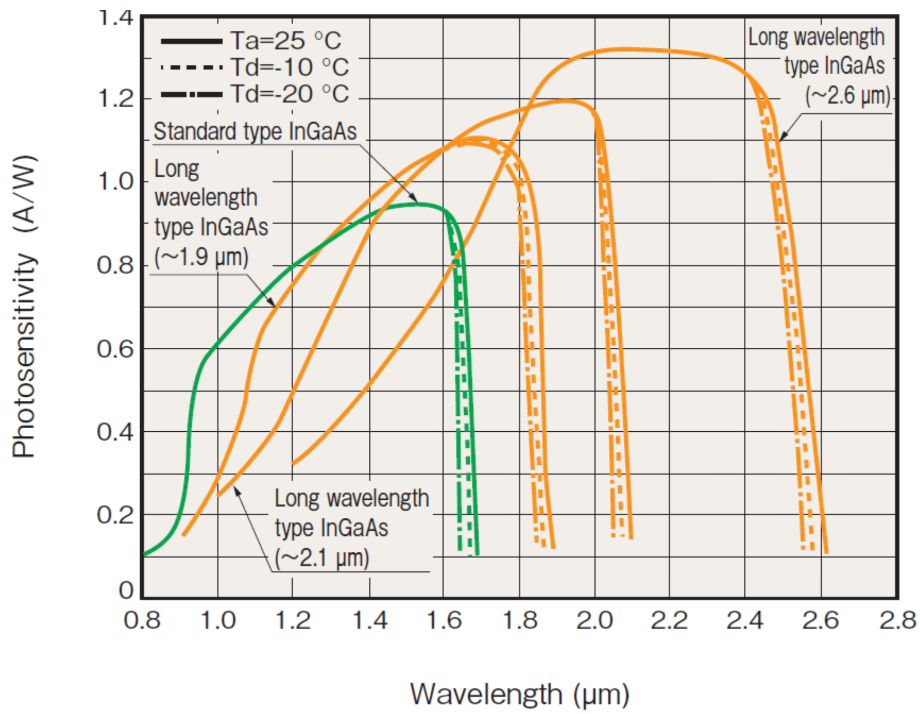
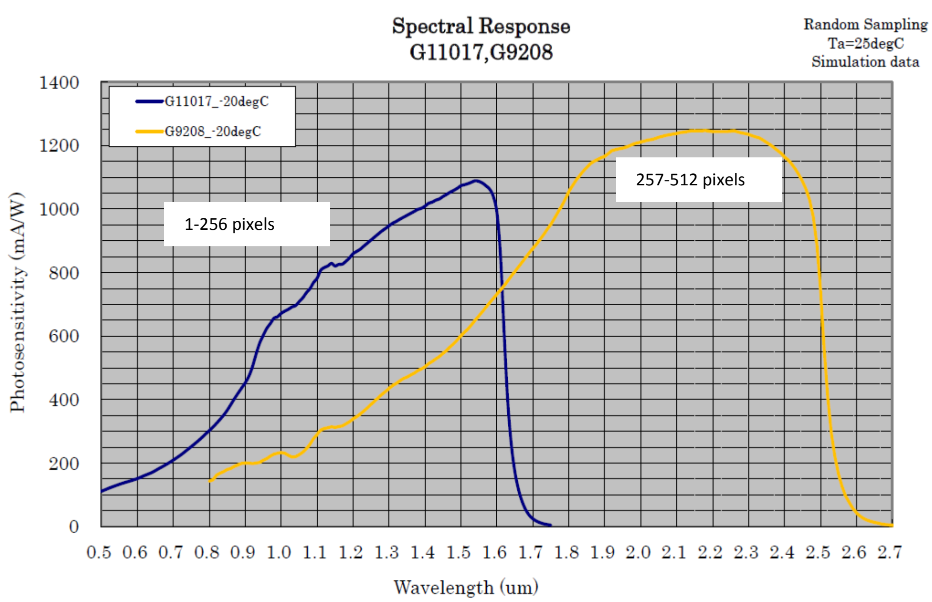


Figure 3: Comparison of the Efficiency vs Wavelength for standard InGaAs (green) and other longer wavelength InGaAs detectors. Long WL InGaAs lose the short WL sensitivity and vice versa.

The challenge is evident from Fig. 2 – no single detector satisfies our needs while each detector only covers a limited spectral range. To overcome this issue, we have developed a new concept (in collaboration with our vendor) for a detector comprising of two different InGaAs chips with different photosensitivities combined into a single chip suitable for use in a spectrometer.



256 pixels

Figure 4: A hybrid InGaAs chip with two different sensitive spectral regions. The PDA contains 512 pixels, with the 1st 256 pixels sensitive to short WL and 2nd 256 pixels to longer WL. The chips are butted up against each other with a limited gap.

<u>Optics and Optical designs for extended Wavelength Operation</u>

Extension of the optics of the ellipsometer to 2.5 um and beyond also requires careful component selection. Reflective Optical designs are used on the ellipsometer and all components including the mirrors, polarizer, and light source operate well to 2.5 um. However, the challenge to extend to 2.5 um for the reflectometer is significant since it employs a beamsplitter which needs to have good reflectance and transmittances across the wavelength. Also, there are few transmissive components (like filters) that would require material engineering to enable operation at broadband level.

Extension of the optics of the reflectometer poses a significant optics challenge because of the normal incidence nature. Operation of the reflectometer requires a beam splitter where the incoming light is reflected as it travels to the wafer and then the reflected light from the beam splitter has to transmit through the same beam splitter. Hence, the throughput of the system depends upon the product of reflectance times the transmission (R*T) as shown in Fig. 5. The current beam splitter has a dielectric coating that has poor performance in the 500nm- 900 nm region. The performance is optimized for 190 nm. For extended wavelength operation, better performance is needed. One option is to use metallic ND filter which have much broader wavelength response. However, metallic ND filters suffer from part to part variation. In this paper, we will describe new approaches to meeting this challenge of provide beamsplitters with high reflectances and transmittances over the broadband wavelength range.

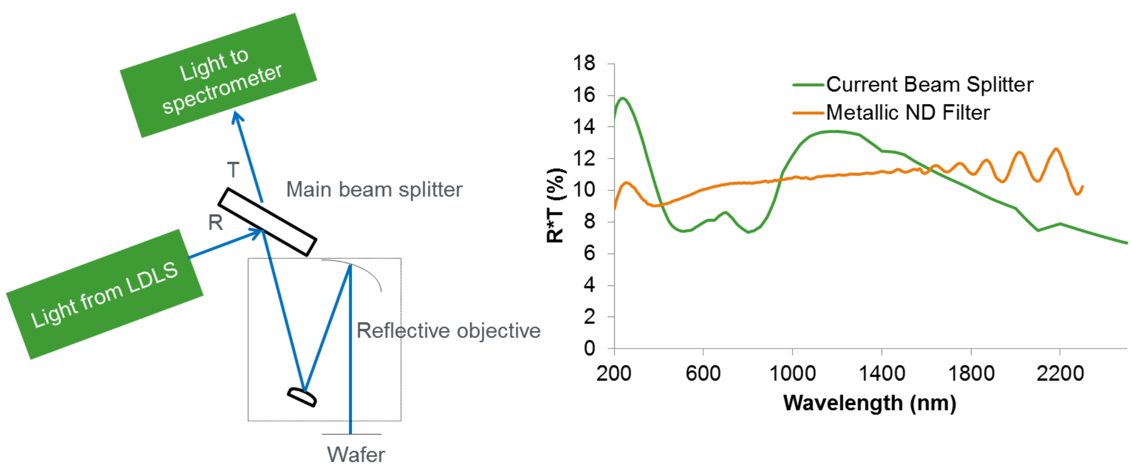


Figure 5 shows the conceptual layout of the reflectometer. It also shows the designs of the current beamsplitter; its performance at wavelengths longer than 500 nm is poor.

Other Challenges and Concluding Remarks

The paper will also provide a look at many engineering challenges including (i) thermal management of InGaAs sensors, (ii) detector performance, (iii) Spectrometer performance and (iv) extension to 3.3 um WL range.

Figure 6 shows preliminary SE spectral results obtained with our breadboard optical system using a hybrid InGaAs detector (2.2 um WL limit for this chip); also included are the results from the standard BBSE optics covering the 190-860 nm WL range. We will provide additional detail on the performance of the system in the detailed paper presentation.

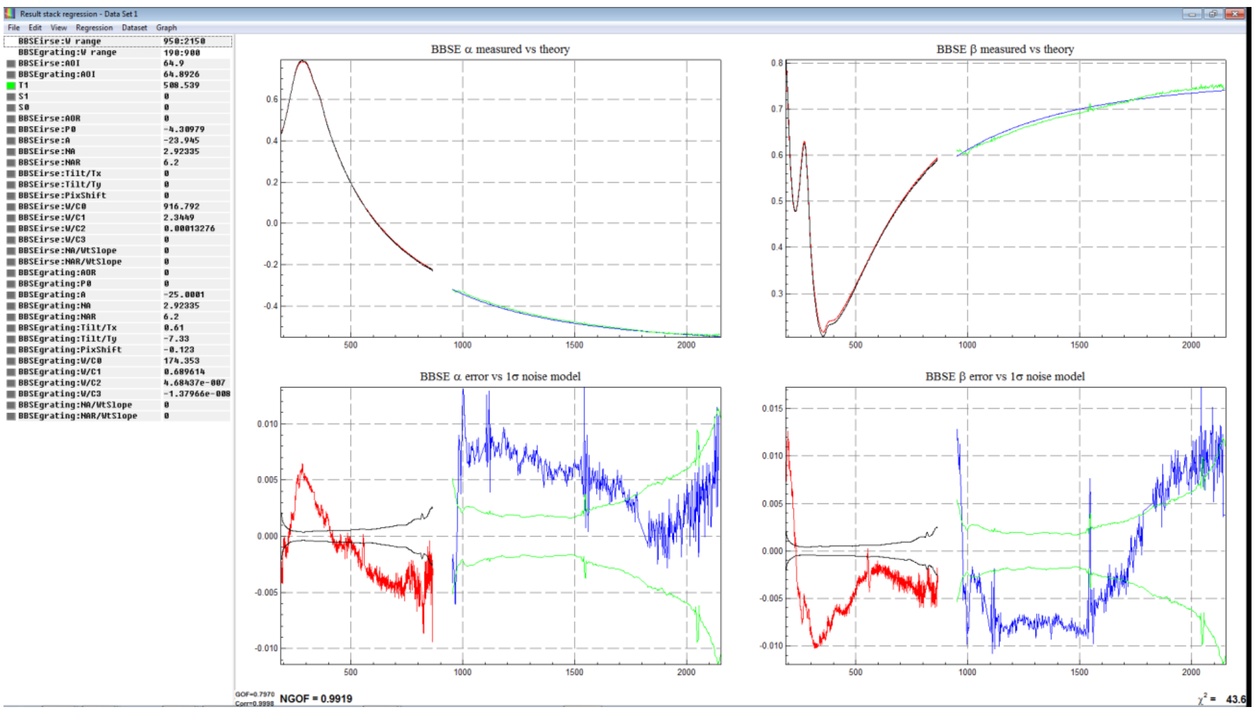


Figure 6: Broadband SE spectral measurements performed on a 500A oxide/Si wafer. The top two plots show the SE Alpha/Beta while the bottom two plots show the error between the measured and the model fit.

In conclusion, we have started to design and develop an IR Spectroscopic Ellipsometer and Spectroscopic Reflectometer systems for 3D Flash metrology. New innovations in spectrometer design, detector development and optical component designs will be presented. It is expected that production-quality SE and Reflectometer measurements will be available later this year and will be presented at the conference.

REFERENCES

1. IRSE 3B Report for Shelby, KTDC-554-547
2. Klaus Flock, “Selective Diffraction With In-Series Gratings, US Patent 08873050.