Overcoming Difficulties in Photoreflectance Measurements on Product HBTs

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Abstract

Photoreflectance (PR) is an optical measurement technique used to study material properties and device structures. It is uniquely able to non-destructively measure electric fields within devices. Some device structures such as HBTs have a rough highly doped InGaAs surface layer. In some cases the surface roughness is sufficient to produce light scattering that impedes optical measurements such as PR. We have developed a new measurement configuration separating the pump laser, which causes the light scattering, from the probe laser. Rapid, non-destructive measurements of the emitter and collector depletion regions are possible with this configuration on product wafers with rough surface layers

INTRODUCTION

The production of heterojunction bipolar transistors (HBT) is a high volume process involving multiple production tools operating 24 hours a day 7 days a week. This production achieves tight specifications and high levels of quality assurance. Quality assurance relies on destructive device fabrication and measurement of individual wafers to indicate the overall quality of production. It is important to reduce the number of product wafers consumed for this testing yet maintain the high levels of quality. This has driven the industry to develop non-destructive measurements of product wafers. Measurements of sheet resistance, particles, and surface haze are commonly performed. We have previously demonstrated the utility of using a fully automated X-ray diffraction tool to monitor the base doping of GaAs HBTs [1]. This is complemented by a new configuration for a photoreflectance (PR) measurement that is able to measure product HBT wafers, which previously produced too much light scattering to be measured.

PR has been used for decades to study material and device properties [2]. The measurement is routinely used to measure band-gap, ordering of InGaP alloys, and electric field. Its ability to measure electric fields distinguishes it from other optical measurement techniques such as ellipsometry or photoluminescence. This ability allows key information about the collector and emitter depletion regions to be analyzed. Production HBTs utilize a rough InGaAs contact layer to reduce emitter contact resistance. This rough layer strongly scatters light, which interferes with the PR measurement.

EXPERIMENTAL

We have found a new measurement configuration that allows a rough sample to be measured and nullifies the problem of the light scattering. The typical PR configuration is drawn in Figure 1. The measurement involves two light sources. Here a red diode laser is used as the pump laser, which is electronically chopped. The probe beam is generated from a halogen lamp with the wavelength selected by a monochromator. The electrons and holes generated by the chopped pump beam modify the electric

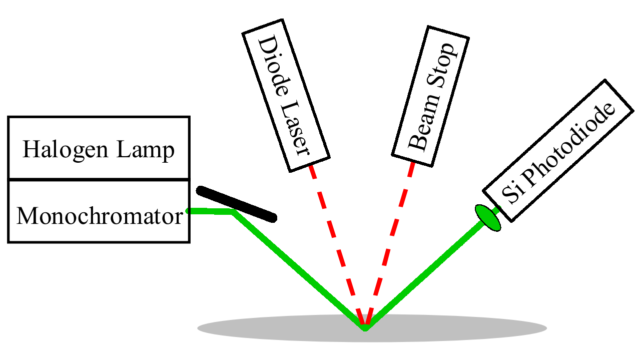

Figure 1. Typical optical layout for a photoreflectance measurement.

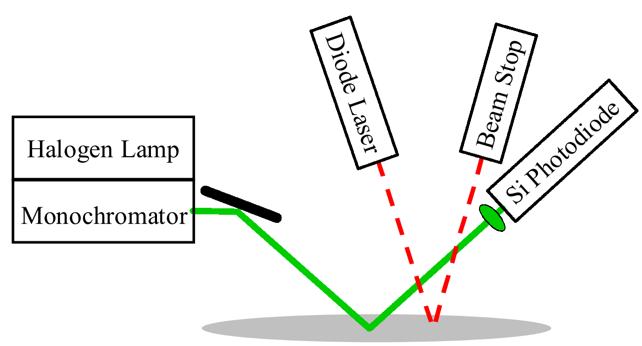

Figure 2. New optical layout for photoreflectance measurement.

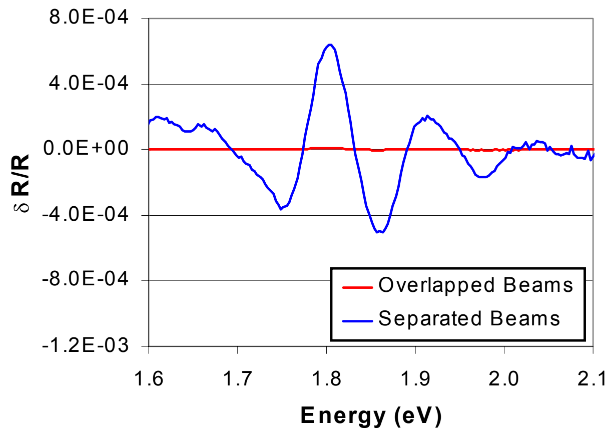

Figure 3. PR signal of product HBT wafer. Overlapped beams shows minimal noisy signal, while separating the beams 5 mm recovers a strong clear PR signal.

fields in the sample. The changing electric fields in turn change the reflectivity that is monitored by measuring the reflected probe beam at the frequency of the pump laser.

PR Configuration and Measurement

The measured signal consists of a large background of photoluminescence, scattered light, and reflectivity. The PR signal is a small fraction of this background. The AC detection technique removes the DC reflectivity. The scattered light and photoluminescence are both modulated by the pump beam and pass through the lock-in detection. These signals are constant through the measurement and contribute a signal offset to the PR signal. This is trivial to correct. The difficulty is that these signals can be much larger than the PR signal. Data acquisition requires a large range of the detection system to keep from saturating, yet at the same time needs to have the dynamic range to measure a very small signal.

For the HBT samples used in this study the photoluminescence is negligible. The scattered light needs to be minimized with respect to the PR signal. We have accomplished this by separating the pump and probe beams as shown in Figure 2. This simple configuration moves the photoluminescence and light scattering away from the position of the sample being probed. The detector is focused on the sample along the reflected probe beam and does not gather the photoluminescence or scattered light from the pump beam.

PR Results

The results of the new configuration are shown in Figure 3. Franz-Keldysh oscillations (FKO) are present, arising from the depletion region of the AlGaAs emitter [3]. In the typical configuration, in which the pump and probe beams are overlapped the signal is virtually nonexistent due to strong interference from the scattered light. The PR signal is recovered by separating the beams a small amount. This signal is then numerically fit to determine a band gap, electric field, and phase. These values are sensitive to changes in layer thicknesses, doping, and compositions in the depletion region. Similar data is obtained from the collector depletion region.

Separating the beams reduces the amplitude of the FKOs. This is shown in Figure 4 where the probe beam was aligned at the center of a 100 mm wafer and the pump beam was moved towards the edge. The PR signal is still resolved with the pump and probe beams 40 mm from each other.

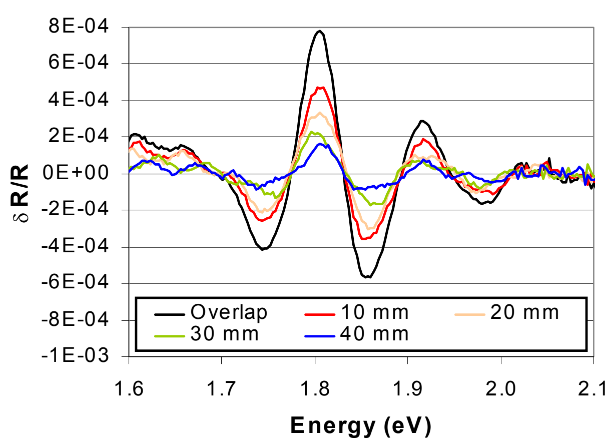

Figure 4. Overlay of the PR signal where the probe beam is in the center of the 100 mm wafer and the pump is moved toward the wafer edge.

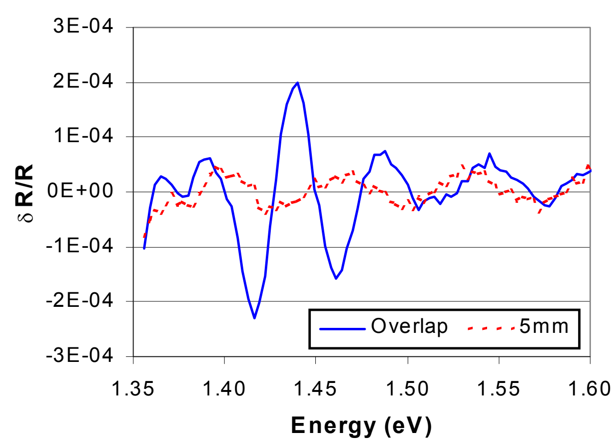

Figure 5. PR signal of undoped GaAs film on n+ GaAs showing strong signal when the beams are overlapped. No PR signal is observed after separating the beams by 5 mm

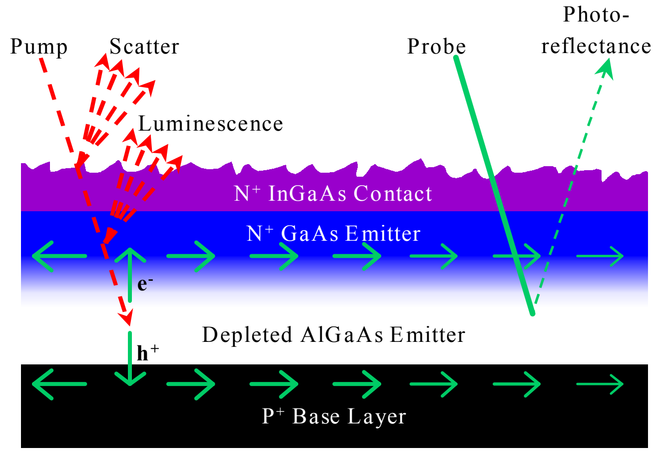

Figure 6. Schematic of carrier generation and lateral diffusion between the pump and probe beams.

Moving the pump beam towards the edge did not change the position, period, or overall line shape of the signal measured in the center of the wafer.

For comparison a structure commonly used in PR investigations is measured in Fig. 5. This structure includes an undoped 200 nm GaAs film deposited on 500 nm n+ GaAs. A clear PR signal is observed when the beams are overlapped using the typical PR configuration shown in Fig. 1. However, separating the beams by 5 mm removes the PR signal leaving a small background.

Discussion

The key difference between the comparison structure and the HBT is the low leakage current across the emitter base junction of the HBT. The pump laser creates electron hole pairs throughout the layers of the structure. In most of the layers these carriers rapidly recombine. The depletion field sweeps carriers created in the PN junctions apart just like in a photodiode or solar cell. Figure 6 is a schematic drawing of this process for the emitter base junction. The electrons are collected in the n+ GaAs emitter, while the holes are collected in the p+ GaAs base layer. These carriers accumulate producing a photovoltage across the PN junction. This photovoltage drives recombination across the PN junction. The wide bandgap emitter of an HBT results in very low leakage currents for the emitter base junction. With this low leakage the carriers are able to diffuse laterally, traversing much of a 100 mm wafer before recombining.

The data in Figure 4 suggests that an effective photovoltage exists for tens of millimeters across the wafer. The effect of the leakage current is to reduce the photovoltage, which is similar to reducing the intensity of the pump laser. Figure 7 shows the dependence of the PR signal on pump power. This indicates that a separation of 40 mm is similar to reducing the pump intensity 75 %.

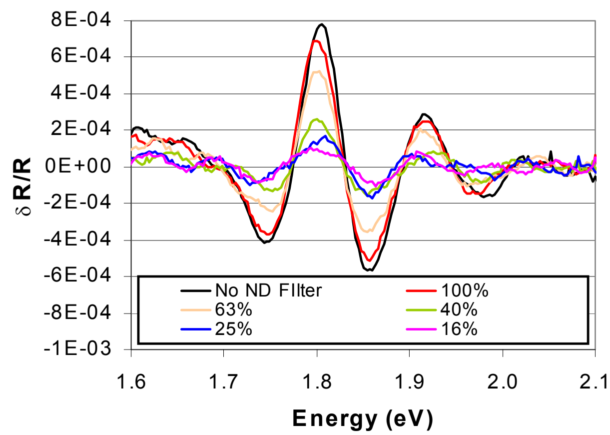

Figure 7. Overlay of the PR signal as a neutral density filter is used to reduce the intensity of the probe laser. The transmittance of the neutral density filter is listed in the legend.

Conclusion

Our data shows that the pump and probe beams can be separated by tens of millimeters in the PR measurement of an HBT wafer. This is not the case for structures in general. Carrier lifetimes are often short and the pump and probe beams must be overlapping to produce a changing electric field in the material to result in a PR signal. The PN junctions of the HBT separate the carriers producing long lifetimes and allow the pump and probe beams to be widely separated. This configuration is shown to be able to measure rough wafers that previously caused too much light scattering to be measured. This capability expands the ability to non-destructively measure and ensure the quality of product HBT wafers.

Acknowledgements

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Acronyms

HBT: Heterojunction Bipolar Transistor
PR: Photoreflectance