Light Emission as an Analysis Tool for GaAs ICs

William J. Roesch
TriQuint Semiconductor, Inc., 3625A S.W. Murray Blvd., Beaverton, Oregon 97005
Phone: 644-3535 ext. 1273 FAX: (503) 644-3198 EMAIL: BillR@TQS.COM

Introduction:

As GaAs IC integration continues, device characterization and failure analysis gets more difficult to perform. Standard visual and electrical inspections are becoming less adequate to evaluate devices and determine root cause of failures. A relatively new technique, used for several years on silicon devices, is light emission microscopy. The properties of light emission on silicon devices have been known for several decades. The light-producing properties of GaAs, a direct bandgap material, make it a natural for light emission study. This overview is intended to discuss the methodology and results of GaAs MESFET light emission.

Purpose:

The intent of this work is to demonstrate the how light emission microscopy can be used to analyze GaAs ICs during characterization, degradation, and wearout. For example, several case studies will be presented to show the emission properties of standard Ti/Pd/Au and Au/Ge/Ni contacts in a MESFET device. Additionally, failed and degraded samples will be characterized as to their light emission properties.

Theory:

Light emission properties of semiconductors have been known for over 40 years.[1] Light emission microscopy techniques were developed for silicon devices in 1986 using "night vision" equipment.[2] Several light emission evaluations have been conducted during this investigation on GaAs MESFETs using Hypervision, Hamamatsu, Zeiss, JEOL, and Barnes/EDO systems. Techniques of light emission microscopy employ detection/amplification of low level photon emission in biased semiconductors. Photon emission occurs in semiconductors under various operating conditions. Some anomalies will generate extraordinary photon emissions. To emit light efficiently, the semiconductor needs to provide a direct path for two different species of charged particles to meet. In semiconductors, the source of charged particles is the normal electron flow (a negatively charged particle) and the production of holes (a positively charged particle). Both electrons and holes are flowing in semiconductor junctions. When holes and electrons collide their energy is released, and a photon is released. This is called "recombination radiation." Silicon is particularly inefficient at generating photons since about a million collisions are required to get a recombination to result in light radiation. On the other hand, a high percentage of electron-hole collisions in GaAs result in the creation of a photon since it is a direct bandgap material. In fact, doping gallium and gallium arsenide with phosphorus, oxygen, nitrogen and/or zinc are standard configurations for common light-emitting diodes.

Light emission is enhanced by several special mechanisms. One of the best conditions occurs during reverse bias. During impact ionization, more of the carriers combine to emit photons. This condition is sometimes referred to as "avalanche luminescence." Hot carriers can also cause photon emission. Tunneling through dielectric films produces light. This "dielectric luminescence" is particularly useful for capacitor anomalies, or MOS device analyses. Large currents in diodes or FETs will emit light during minority carrier recombination, even in silicon devices. This is called “forward biased emission” for standard operation, and referred to as “Saturated N-Type Emission” for the highest current condition. Lastly, the evaporation of materials in an anomalous structure will results in “thermal radiation” of these extremely hot areas involving whiskers, stringers, or other types of filaments.

Equipment:

Even though charged particle collisions in GaAs are efficient at generating photons, special microscope technology is needed to observe the emission. Two primary types of emission detection are commonly utilized. Original light emission microscopes were developed using image intensifier tubes. These tubes were originally developed for infrared or “night vision” applications. Some light amplification tubes are capable of multiplying photons by more than a million times. More recently, Charge Coupled Device (CCD) cameras have been enhanced to detect lower and lower levels of photon emission. Both these types of detection often utilize cryogenic cooling to decrease background noise and improve sensitivity.

In this study, a total of five different light emission microscopes were tested. The first CCD type is by Hamamatsu. Their “PHEMOS” series of microscopes use a 1000x108 dual mode CCD camera. The second CCD type is by Zeiss. It integrates a liquid-cooled CCD with 1024x1024 pixels. The third CCD type is by JEOL. Both the JEOL and Zeiss systems are built into laser scanning microscopes which are also capable of Optical Beam Induced Current (OBIC) imaging.

The light amplification types of microscopes investigated were: Hypervision and Barnes (formerly KLA). Both of these systems actually use dual cameras. The first is a standard CCD type for typical reflected light imaging. The second camera is integrated with the Image intensifier apparatus for maximum sensitivity. Several generations of these amplification microscopes utilized the same detectors, but the manufacturers have more recently diverged in their approaches.

All manufacturers claimed superior imaging ability. In side-by-side tests of a reference device, each system was capable of detecting both forward and reverse biased emission. None of the systems was found to be particularly superior or inferior to the others. The author did notice that the overall image quality of the CCD-type systems was better, and the ability to perform OBIC and digital imaging with the laser scanning systems was a definite advantage that might be worth the additional expense.

Figure 1 shows some comparisons between three of the manufacturers in terms of their spectral and sensitivity performance. For the most part, the various microscopes make small trade-offs between sensitivity and bandwidth. The CCD type microscopes can detect over a wider range of emissions, and the intensifier type microscopes have more sensitivity, but over a narrower range of emissions.

Results:

Light emission on GaAs devices can be observed without light amplification. High speed film, exposed for long time periods, can detect emissions. However, real-time detection requires light amplification. In this study, light emission intensity was found to be most strongly related to current. While under reverse bias, small currents were found to be adequate for generating a lot of emission. More current is necessary in the forward direction to cause emission.

Figure 1. Sensitivity and Wavelength

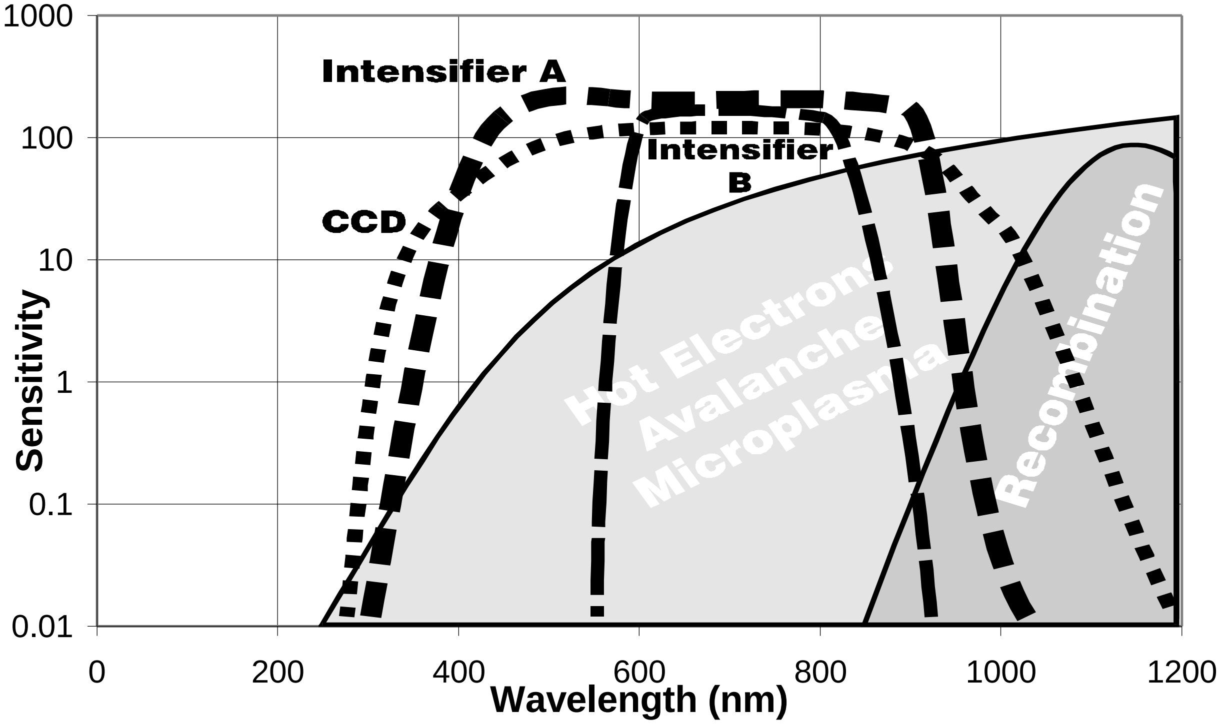
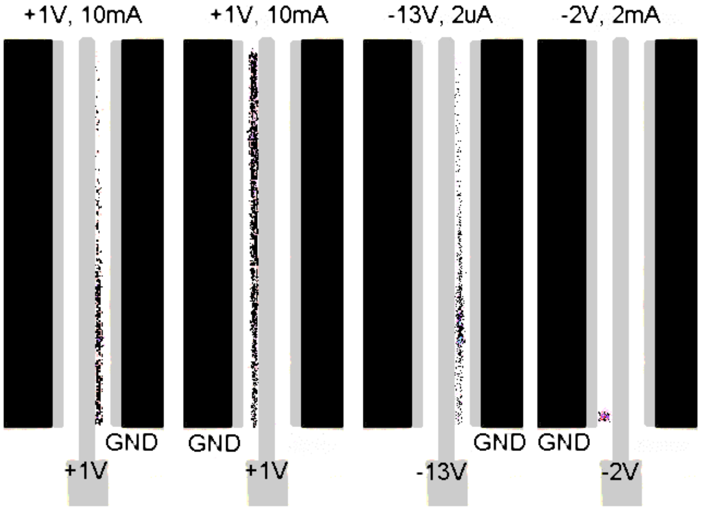


Figure 2 shows typical emission patterns for MESFET gates operated in forward and reverse bias modes. While these images were gathered with the FETs operating as diodes, the emission patterns were found to be additive when both source and drain were biased. Normally, no emission was detected if there was no gate current. Current flow in the channel itself was not sufficient to generate emission, unless there was an anomaly.

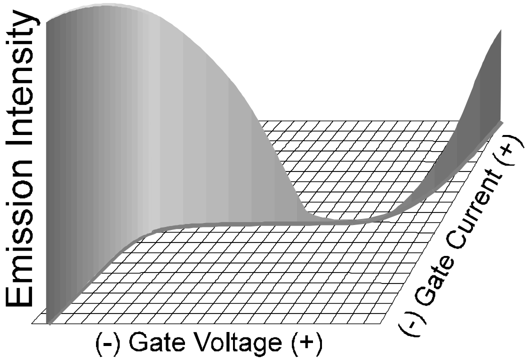
Figure 2. Typical MESFET Light Emission for Several Gate Biases.
(Un-labeled terminals were left floating)



For the most part, general emission in GaAs FETs is distributed along the channel. Forward biased emission was always observed as a distributed emission with a uniform distribution. Emission patterns under reverse bias are much more variable. Some reverse bias emission patterns were remarkably similar to forward bias, particularly for very low leakage devices. As leakage current increases in the reverse direction, the sources of light emission typically become smaller and brighter. Some anomalies were found to be very small and very bright.

Figure 3 shows the relative emission observed on a typical Schottky diode bias response. Emission in the reverse direction provides more intense emissions once gate current begins to flow.

Figure 3. Relative Light Emission Vs. Gate Bias.



Anomalies:

The first anomaly observed in this study was a result of overstressing the sample used to characterize various microscopes. In general, the reverse bias required to cause current flow is dangerously close to breakdown levels for most FETs and diodes. If the experimenter tries to get additional emission by increasing the bias levels, catastrophic breakdown may be the eventual result. Once the overstress occurs, the structure is an excellent emission source. Emission microscopy has been used successfully to detect ESD/Overstress damage on devices returned from the field.

Because the emission microscope is very efficient at detecting reverse bias emission of Schottky contacts, several samples have been examined in an attempt to isolate causes for very high leakage current. Investigation of particularly leaky devices always discovers point sources of light emission. See Figure 4. Some devices exhibit a single light emission source, and some devices have multiple point sources. Using the emission microscope, several point sources were de-processed and found to correlate to physical anomalies under the gate - a valuable clue to help in the corrective action.

The light emission microscope has also proven to effectively track down metallization anomalies. Three types of anomalies have been observed. Stray metallization particles (often produced by liftoff patterning technologies) which electrically bridge conductors act as filaments for thermal radiation which occurs around these hot areas. Another anomaly that has been detected involves fuses. A partially blown nichrome laser link is another filament-type structure that results in localized thermal radiation. The last type of metallization anomaly observed to emit light is an ohmic contact which has been damaged by chemical and plasma exposure during fabrication.

Figure 4. Anomalous Light Emission on a Leaky Gate.

In spite of all the anomalies and nominal luminescence detection capabilities of emission microscopy, there are many limitations of the technique. In most cases, the emission source itself must be observable. For multilayer metallizations, many emission sources are covered by subsequent metallization layers. Specific investigations involving Schottky gate wearout do not result in any particular emissions. For example, MESFETs with severely degraded gates do not create abnormal light emission. Similarly, MESFETs degraded by hydrogen do not emit light in an anomalous manner.

Impact:

The results of this work demonstrate the techniques of light emission microscopy and it's use to characterize, evaluate, and analyze GaAs circuits.

References:

[1] Photon Emission from Avalanche Breakdown in Silicon, K.G.McKay, "Photon Emission from Avalanche Breakdown, A.G. Chynoweth & K.G. McKay, Phys.Rev. (1956), Vol.102, No. 2, Pg. 369.

[2] Analysis of Product Hot Electron Problems by Gated Emission Microscopy, N. Khurana & C-L Chiang, International Reliability Physics Symposium, 1986, pg. 189.