Method for Detecting GaAs Die Fractures in Device Manufacturing Through the Use of a Designed Test Vehicle

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Abstract

Substrate fracture is a common failure mechanism for GaAs products. In most cases, fractures can be detected and rejected by electrical final test. At a low occurrence rate, however, some fractures can go undetected. The fractures may not cross a circuit component in which case the electrical circuit is not disrupted or the circuit metallization may not fracture with the GaAs. A test structure was designed and implemented on a dedicated test vehicle to detect fractures even at a low occurrence rate. The test vehicle makes use of a thin, brittle metal line patterned in a serpentine fashion over the surface of the die. The metal line is electrically testable with a simple resistance measurement so large quantities of devices can be tested in order to produce a suitable sample population. By using the test vehicle, the manufacturing process can be monitored and fracture-causing processes can be improved.

INTRODUCTION

In the manufacturing process for GaAs devices, there are multiple risks for the device to be fractured due to the brittle nature of the die substrate. Fractures could result from any process step, but the die is obviously more susceptible once the wafer is thinned. Die fractures are most commonly a result of issues at singulation (wafer saw), tape transfer, die bond, wire bond, package singulation, test or any other physical handling step. [1, 2] In most cases, a fractured device fails final electrical test, however, instances where a fractured device could pass electrical test exist. In some cases, a fracture may not cross any circuit component which would cause a failure. In other cases, the fracture may occur in the GaAs, but the metallization above does not separate. This is an inherent difference between GaAs devices and products which use silicon (Si) as a substrate material. The GaAs and EPI semi-insulating substrate can allow a fracture to occur without disturbing the device. In essence, the defect will not be detected for GaAs products but for Si devices, a similar fracture will result in a short circuit. In cases where a fracture reaches the surface, the standard Au top metal can often stretch over this gap and the part can still function depending on what structure has been fractured. The result is an unpredictable rate of failure at the customer site. The fracture will often increase during the device reflow process on to the circuit board. The increased fracture can then cause a passing final test part to be an electrical failure at the board level. In a worst case scenario, the fracture will only grow large enough to cause a failure when it is in the field.

See Figure 1 which shows an example of a fracture in areas that were non-critical, under metallization, and through a circuit component. In this instance, the fracture caused a shorted capacitor, but the metal interconnect lines were all still functional.

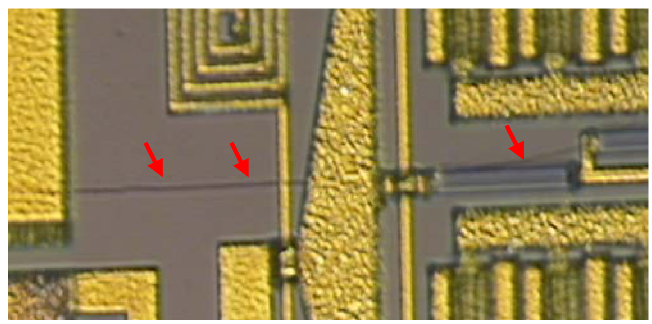

Figure 1: Example die fracture

While the level of defects may be very low, customers demand zero defects in order to satisfy the requirements for their own assembly yields and long term reliability. Customers are also sensitive to fractures in GaAs products because it has been an industry-wide problem since the inception of these materials. There is always a desire for continuous improvement in this area. [3]

PREVENTION

There are two ways to prevent customers from receiving fractured devices. The first is to screen out the bad devices through the use of rigorous inspections at each of the various process steps from wafer manufacture to final product test. This is, in the long run, not a viable manufacturing concept and is often not effective at detecting all defects. In addition, since most GaAs devices use epoxy die attach material and are overmolded, visual, x-ray and CSAM inspections provide no real process oversight after the overmold process step. The second, more proactive approach is to improve the processes so that even low occurrence fractures do not happen. This approach may be facilitated by the use of a test structure or vehicle that is sensitive to fractures of any size and has the ability to detect fractures at any stage during the manufacturing process from wafer probe to final test.

DESIGN CRITERIA

A die crack detection test vehicle needs to meet certain criteria. First, it would use a standard wafer process (EPI, thermal vias, metal depositions layers, etc.) typical of a GaAs device structure. By using the standard process, the stresses on the test die can be as close to a product die as possible. Second, it would use a standard package platform so it may adequately check the processes at the assembly site. Third, it must have the ability to be tested electrically and produce a suitable response which would indicate fractures. This feature is critical because low level defects can only be found when the volume of parts tested is sufficiently high. A logically designed circuit and test scheme could detect not only the existence, but also the location of a die fracture thereby, eliminating the need for detailed visual inspections and lengthy deprocessing. Finally, the test structure or vehicle needs to have circuitry covering a high percentage of the die area, and this circuitry must be brittle enough to fracture if the GaAs fractures. This ensures that fractures anywhere on the die will cause an electrical failure. It is also helpful, though not necessary, for the die size and pad layout to mimic existing products so that the test vehicle can be processed identically to product.

IMPLEMENTATION

A test vehicle was designed to meet these criteria. The layout image and photo of die is shown in the Figure 2.

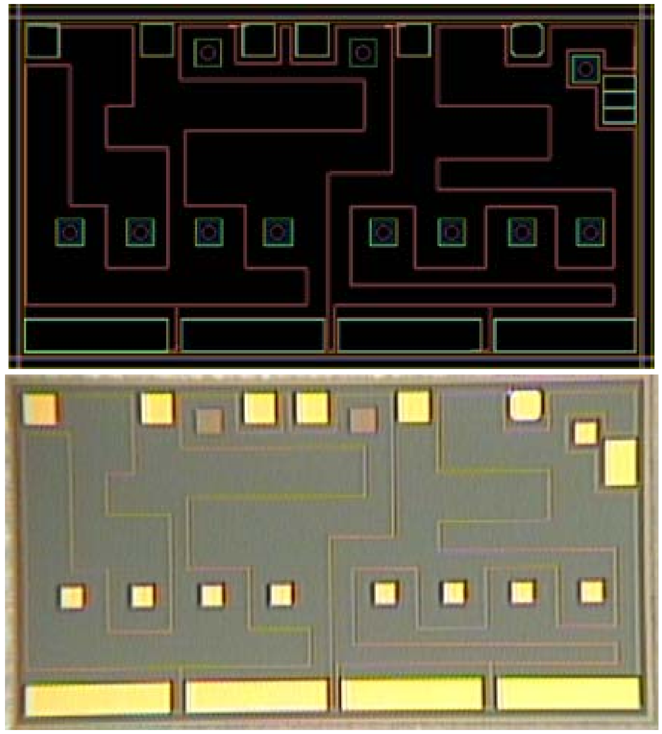

Figure 2: Image of the test vehicle layout and die

The die size, bond pad pattern and through-wafer-via pattern duplicated the product die so that the assembly process and response could match standard production. This also allows for an easy transition between production and the test vehicle prior to, during, or after normal production runs. On the surface of the die, the fracture sense metal is patterned in a serpentine fashion around the die area as well as the die edges. The metal layer used is a thin, brittle film that is sensitive to cracks and is a commonly used layer in the wafer process so it could be implemented easily. The fracture sense metal line is connected to each bond pad in a fashion that enables independent detection by electrical test at these locations, thereby allowing an interpretation of fracture location once the bond pad has been separated from the rest of the circuit. In this particular case, the device is packaged in a multi-lead package so that all individual bonds could be externally probed. Following standard wafer fab processing and then package assembly processing, a large volume of parts could then be generated and subsequently tested.

The test program developed for this design is a simple resistance measurement, forcing voltage and measuring current, R = V/I. See Figure 3 which shows the measurements of good devices across multiple voltages.

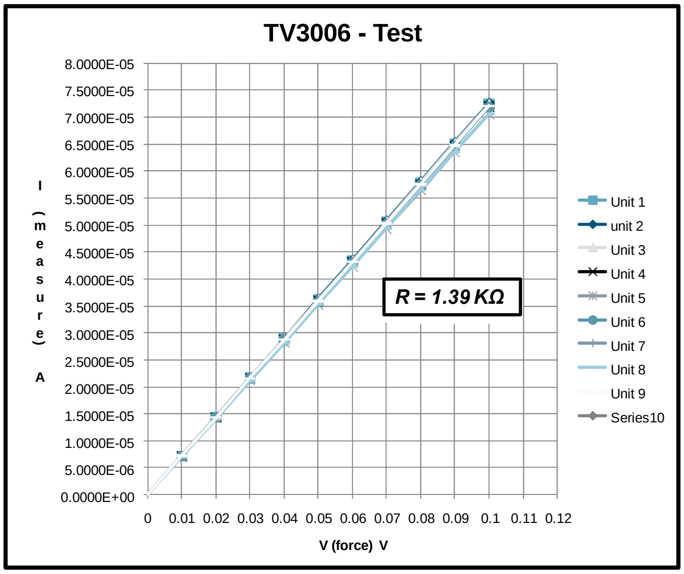

Figure 3: Measurement data of test vehicle die

A break in the metal line results in an open circuit. With a finished product, the test may be manual (probe) or programmed into automated test equipment (ATE). The latter is preferable and essential for large volume test of low occurrence events. For the test vehicle used, the test program was setup to determine numbers of open circuits and the locations of fracture per unit tested.

APPLICATION

The application of this test vehicle is two-fold. First, it can be used to monitor the production process and determine the fracture failure rate and processes which cause the fractures. This is most useful in the assembly and test factories, but can also be used in the wafer fab. Second, it can be used for process improvements at these factories. If a specific process is a risk for die fractures, experiments can be run using the test vehicle to determine the optimal conditions. The application of the concept can also be implemented on live products where die can be designed with the fracture detection circuit included. This would allow final test to reject fractured die.

CONCLUSIONS

Freescale has successfully demonstrated use of the test vehicle through the manufacturing process and electrical test. Significant volumes, in the thousands of units, were studied. Under standard processing conditions, no failures were observed. Moving forward, we will use the test vehicle for significant process changes and we are also applying the concepts to production designs.

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ACRONYMS

ATE: Automated Test Equipment
CSAM: C-Mode Scanning Acoustic Microscopy