Moiré Stabilized Thermal Imaging

J.B. Colvin
FA Instruments, Inc.
2381 Zanker Rd., Suite 150, San Jose, CA 95131
Phone: (408) 428-9353 Fax: (484) 210-2961 Email:jim@fainstruments.com

1. Introduction

Today's multilayer technologies serve to limit the ability to detect defects or map power consumption. Traditional thermal imaging methods typically utilize a background reference image with no bias, and then a subsequent biased image is acquired and compared. The length of time to acquire is typically seconds, resulting in thermal propagation across the die before enough signal is obtained to realize a useful result. A new method of backside thermal mapping based on the relationship between mechanical strain and local interference pattern shifts will be shown for the first time. Sensitivity will be shown to be far superior to IR camera imaging methods and comparable to Fluorescence Microthermal Imaging (FMI), allowing entire array blocks with low power consumption to be identified.

This new method of acquisition controls synchronously the thermal propagation, while building up the thermal signal to enhance the Moiré pattern sensitivity.

2. Experimental Details

Moiré thermal pattern imaging is generated by illuminating standard thinned and polished silicon from the backside with a monochromatic laser flood source optimally between 1064nm and 1400nm [1,2]. A high speed CCD or InGaAs camera is used to collect the frame data. Interference fringes are observed which can be mathematically compared pixel by pixel for different powered states of the device. Fringes form from the resultant interference patterns locally associated with the thin silicon film. The film thickness needs to be 100um or less with 30 to 50 um optimal. Local thermal events cause thermal strain thus shifting the position of the interference bands locally. The difference signal is built up using the new Stabilize method. This method operates with controllable numbers of State 1 and State 0 frames. For Stabilize 1x, the DUT alternates between States 1 and 0 for every frame. For Stabilize 2x, the DUT alternates between States 1 and 0 every 2 frames, and so on. Stabilize can run any binary multiple.

The process is as follows, using Stabilize 2x as an example. Equation 1 is used for Moiré thermal mapping to monitor subtle shifts in the interference patterns with alternating biasing:

$$\text{Frame} = \left| \sum_{n=0}^{N/2} (\text{State 1 Frames}) - \sum_{n=0}^{N/2} (\text{State 0 Frames}) \right| \qquad (1)$$

The absolute value is taken for the result to enable mapping of the change regardless of whether the change was positive or negative. Without this, half the fringes will not display after subtraction. By changing from 2X to 4X stabilize, it becomes apparent that the thermal propagation has been increased to a summation of 4 frames on, 4 frames off, 4 frames on… and so on, until the signal has been built up to the desired value. The end result will be N accumulated frames in packets of 4. No Lock-In amplifiers are required for this technique, since the frame rate is already synchronously timed to the device being analyzed [3]. Most traditional infrared imaging methods do not address thermal stability and drift issues and only compare a background reference image with no bias, to a subsequent biased image. The length of time to acquire is typically not well controlled, resulting in thermal propagation across the die before enough signal is obtained to realize a useful result. By controlling, at high speed, the device bias modulation synchronized with the frame rate, the signal can be sampled and accumulated until the signal is sufficient for viewing. The interface can trigger with a test sequence in slave mode or drive the modulated power directly to the device. Devices which cannot tolerate full power down, such as vectored IDDQ failures, can be modulated between a minimum and maximum sustaining voltage enabling the acquisition of the thermal image without losing the present logic state of the device. This stabilize method of acquisition is also compatible with Infrared imaging systems and FMI. The ability to visualize and control the propagation per unit time gives insight as to the location and nature of the defect and its surroundings.

3. Implementation

The monochromatic source chosen was an UltraSpec III from UltraTec operating at 1064nm with a standard fiberoptic illuminator connected to an FA Instruments CCD based emission microscope platform. The Ultraspec blends the laser radiation through a spinning rod to nullify the coherent nature of the laser. The phase blended monochromatic light was then injected into a standard fiber optic bundle to the microscope and used as the flood source. The microscope must be suitable to image with a monochromatic source coaxially in order to avoid viewing imperfections in the optical path. The software based process switch control was used to control the device bias synchronously. Detrimental localized thermal or recombinant injection into the die was avoided, since a flood source rather than a rastered laser scanning microscope was used. Total injected radiation into the die is less than a bulb source yet brighter to the CCD as only the desired wavelength comprises the total energy. The device to be tested is controlled by the process switch from the FA Instruments software. A solid state relay is used to control the bias state for this particular failure with a software paced switching speed of 33 mSec or more. The stabilize process; camera and bias control are all controlled synchronously from the same software to ease implementation of the technique.

4. Results

A comparison to traditional and Stabilized FMI on the same die allows characterization of Moiré thermal. Traditional FMI is implemented using a fluorescent compound (EuTTA) irradiated with UV. The device is imaged with bias on and again with bias off. The change in brightness is determined by subtraction of the off state from the on state since the effect is inverse. Thermal sensitivities are on the order of 10 mK, but the technique is only useful for front side analysis, due to the proximity requirements of the thin film [4]. Thermal propagation through the die reduces the efficacy of the technique due to the slow scan read of a full frame sensor as shown in Figure 1. Note the lack of contrast due to lateral heating. Figure 2 is the same device using 4x stabilize and 256 synchronously summed frames termed SFMI (Stabilized FMI). Figure 3 contains side by side images of the FMI signal without the background overlay. Note the dramatic difference between traditional FMI and the Stabilize method wherein the current path through the die is evident, due to heating. Figure 4 is SFMI using a 20x objective. The same part was epoxy filled from the topside and prepared for backside Moiré analysis in figure 5 to facilitate the comparison. The power required to image this particular defect was 1mW for both the FMI and Moiré techniques. Detection limits will vary based on the localized resistive nature of the defect and the proximity to the thermally conductive substrate. Figure 6 shows the location of the identified sputter defect responsible for the leakage at the metal 1 layer.

Another die was analyzed with an IDDQ failure as shown in figure 7. The bias was cycled from 1 V to 4V in order to maintain the standby condition. This failure was associated with a row decoder drive block. This failure was found only with Moiré thermal pattern imaging as no photon emission was observed due to operation in the linear region. The failure was also non responsive to the various thermally laser induced stimulus methods. Normal infrared imaging was also not successful due to the low power level of 1 mW spread across a 200um^2 area.

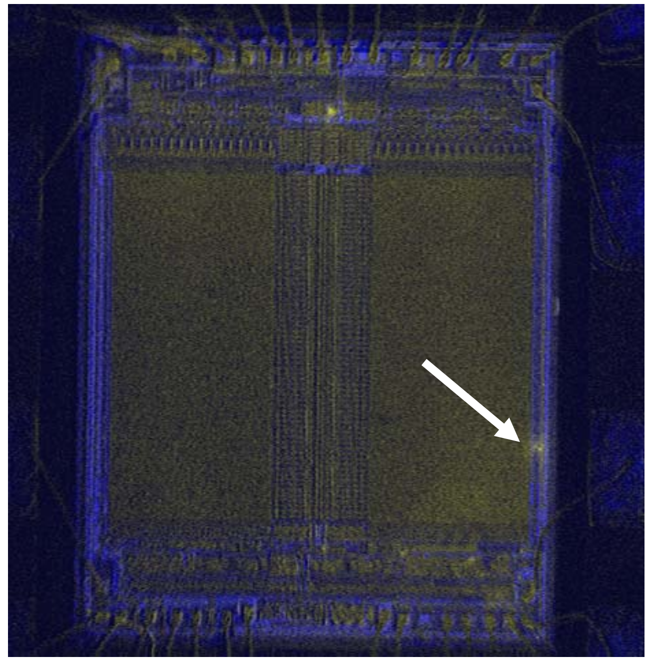

Fig. 1: Normal FMI on 4x5mm die

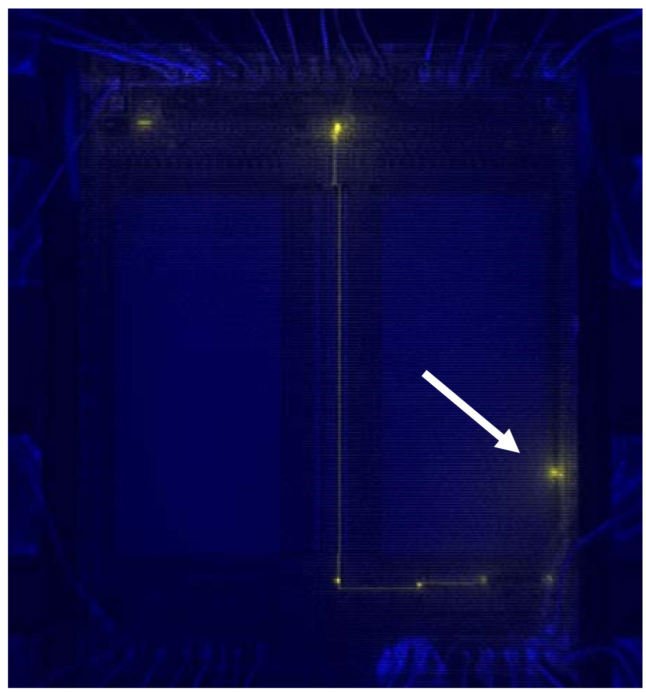

Fig. 2: Stabilized FMI on 4x5mm die

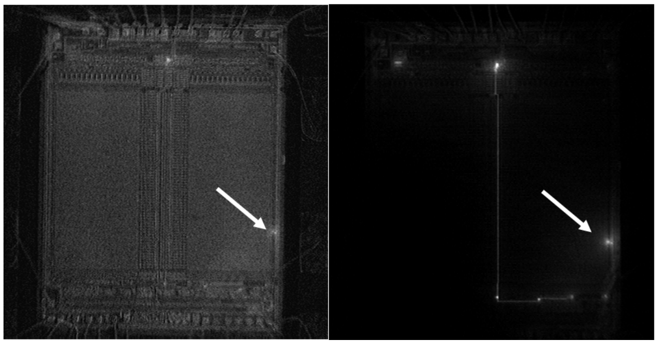

Fig. 3: FMI vs. SFMI on 4X5mm die

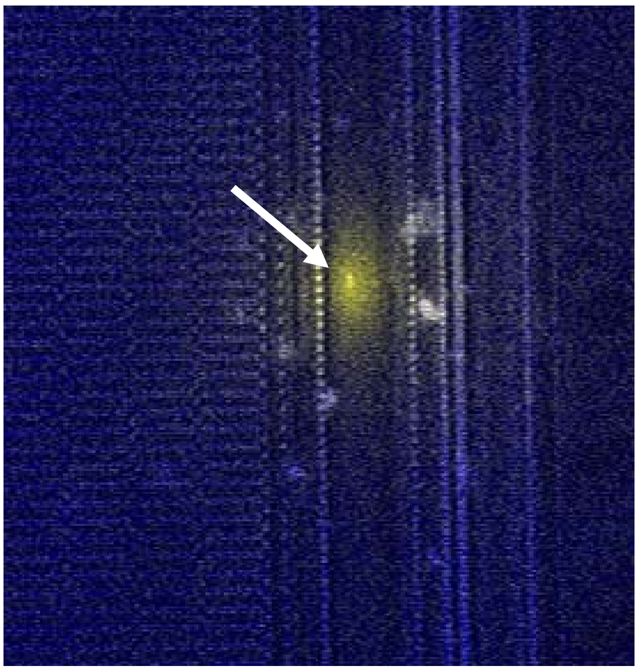

Fig. 4: 20x objective of detail from figure 2

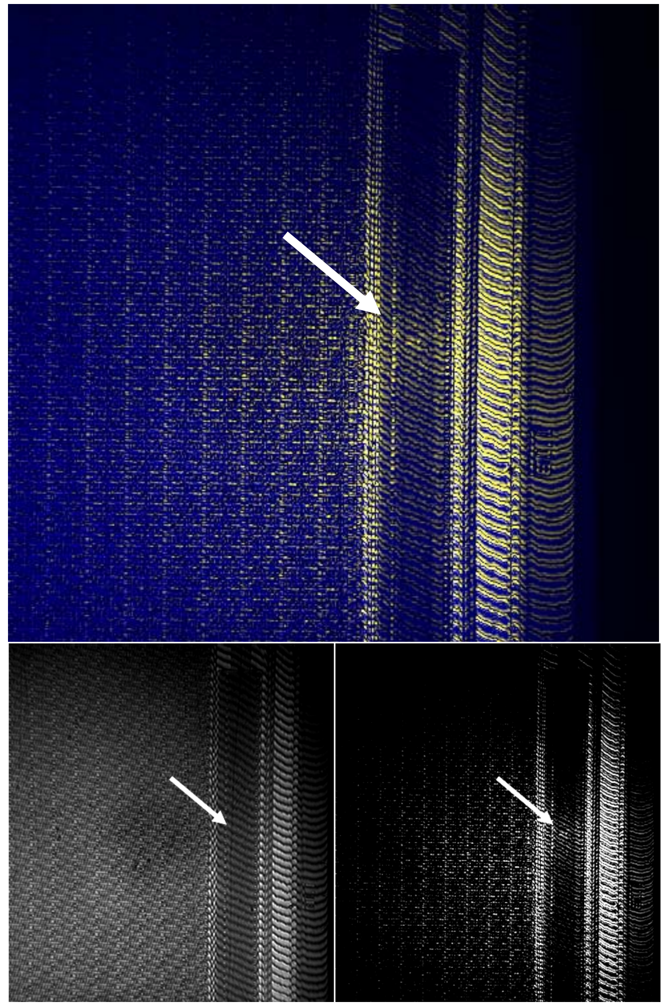

Fig. 5: Moiré thermal pattern image. Overlay above, image lower left, thermal pattern lower right

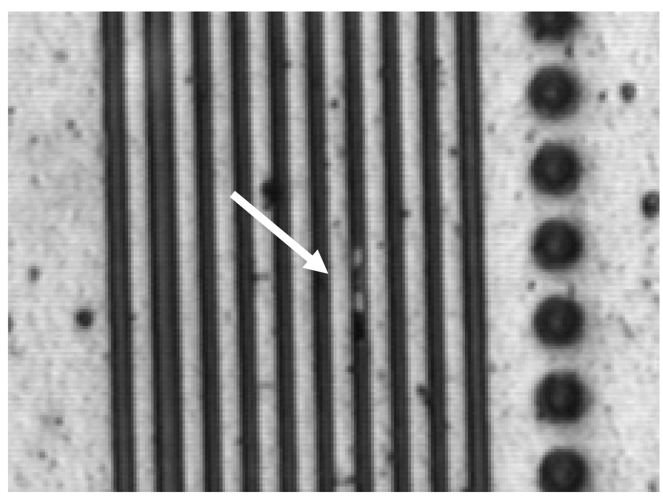

Fig. 6: Sputter Defect Responsible for Failure

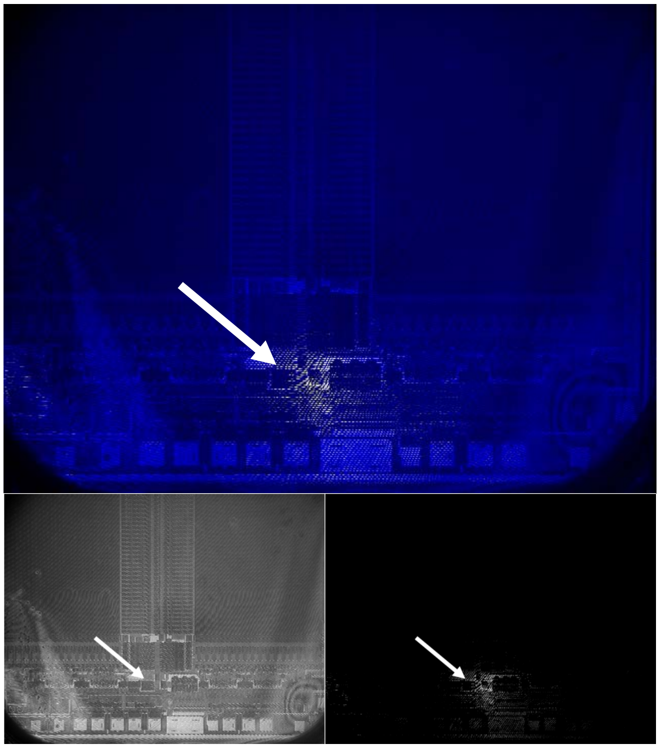

Fig. 7: IDDQ Failure. Overlay above, image lower left, thermal pattern lower right

5. Discussion

Detection limits will vary based on the localized resistive nature of the defect and the proximity to the thermally conductive substrate as mentioned above. The sensitivity of this technique is not based on current; it is based on power density. Sample preparation affects the spatial resolution of Moiré thermal. Since the technique relies on mapping the change in fringe location, it becomes evident that fringes spaced closer than the line pair resolution of the chosen objective will become problematic for detection. Likewise, fringes which are broadly spaced will limit the resolution. Generally, a small amount of tilt during sample prep is desired. The author does not recommend implementation of this technique on a traditional laser scanning microscope due to the frame sampling rates required to build the signal coupled with the intense beam required to sample above the noise floor. The UltraSpec laser flood illumination source is key to implementation of Moiré imaging without local heating from the laser.

6. Conclusion

The interference fringes observed associated with backside imaging of silicon with monochromatic laser radiation have been shown to be a useful thermal strain gauge for mapping local thermal anomalies in integrated circuits. Sensitivities on the order of 50 mK have been demonstrated by comparison to FMI methods. Moiré thermal mapping is exceptionally useful for identifying IDDQ or core standby issues, important for battery operated devices. Not only can defects be identified, but design debug is enhanced with backside power mapping capability. The controlled thermal propagation based on the stabilize factor is key to extracting pertinent thermal data from the noise. Stabilized thermal imaging allows not only greatly improved thermal detection but control of the amount of heat propagating from the thermal source.

References

[1] J.B. Colvin, United States Patent US6112004: Emission Microscopy System and Method.

[2] J.B. Colvin United States Patent US6134365: Coherent Illumination System and Method.

[3] O. Breitenstein, et al, "Fault Localization and Functional Testing of ICs by Lock-in Thermography", Proc. 28th ISTFA, pp. 29-36, 2002.

[4] D.L. Barton, "Thermal Defect Detection Techniques", ASM Microelectronic Desk Reference Fifth Edition, pp.378-397, 2004.

Acknowledgements

To Roberto Collins for valuable input and review of this manuscript and to my wife for her support and patience with my burning the candle at both ends.