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AI-Powered Terahertz VLSI Testing Technology

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ABSTRACT

Many of today's Very Large Scale Integration (VLSI) chips are digital designs that have hundreds of thousands to millions of transistors per chip. Testing of such large VLSI chips proves to be a challenge. The growing complexity of digital and mixed-signal systems makes it increasingly challenging yet vital to develop robust methods to assess and confirm the reliability and authenticity of ICs.In this report a new terahertz testing method has been introduced for non-destructive and unobtrusive identification of counterfeit, damaged, forged or defective ICs by measuring their response to incident terahertz and sub-terahertz radiation at the circuit pins and analyzing the response using artificial intelligence (AI). These responses create unique signatures for ICs. 2D images were generated by measuring the response on a selected pin of a radio frequency IC (RFIC) scanned by a focused terahertz radiation. By applying the data augmentation processes, a secure image data set was created to train the convolutional neural network (CNN) model. An unsecured image data set representing altered or damaged ICs was generated by modifying the original image data. The trained models identified secure devices with a ~94% accuracy.

Keywords- Scale , Integration, Chip, Frequency

INTRODUCTION

With their ever-increasing complexity electronic devices and circuits have become more prone to various security threats. Deliberate alterations can be introduced to highly complex integrated circuits (ICs) at the design, fabrication or packaging stages. Unintended materials and device failures can happen due to the effects such as limited lifetime, premature material deterioration, and unpredicted external conditions. Finally, legitimate components and systems can be replaced with the counterfeit ones during shipments.

Terahertz radiation for inspection and fault detection has been of interest for the semiconductor industry since the first generation and detection of THz signals. Until recent hardware advances, THz systems lacked the signal quality and reliability for use as an effective nondestructive testing (NDT) method. Semiconductor inspection and verification methods ensure the functionality and thereby safety of vital electronics for several critical industries. invariant mass of the photon is zero, it always moves at the speed of light in a vacuum and exhibit wave-particle duality. At low terahertz radiation intensities, the DC voltage will be proportional to the intensity, while at high terahertz radiation intensities, it will likely be proportional to the intensity's square root.A new approach of terahertz testing of monolithic microwave integrated circuits (MMICs) and VLSI circuits is possible by measuring the circuit's DC bias responses at the pins or input/output contacts or leads and then analyzing these responses with etalon responses. Minor biasing modifications may also trigger significant changes to the transistor's response, which improves the usefulness of the approach. Voltages induced by terahertz or sub terahertz radiation at the IC terminals can be used as a diagnostic mechanism for defects or deviations from the expected outcome. Such voltages may form specific signatures of defects. This method can also predict the lifetime and reliability following the fault diagnosis and identification process. At low terahertz radiation intensities, the DC voltage will be proportional to the intensity, while at high terahertz radiation intensities, it will likely be proportional to the intensity's square root or saturate. For transistors with defects, such as high leakage currents, for instance, this response will be very different. Usually, the transistor gate size specifies the spatial resolution of this defect-detection technique. Additional testing details can be achieved when the impinging terahertz beam is scanned through the circuit.

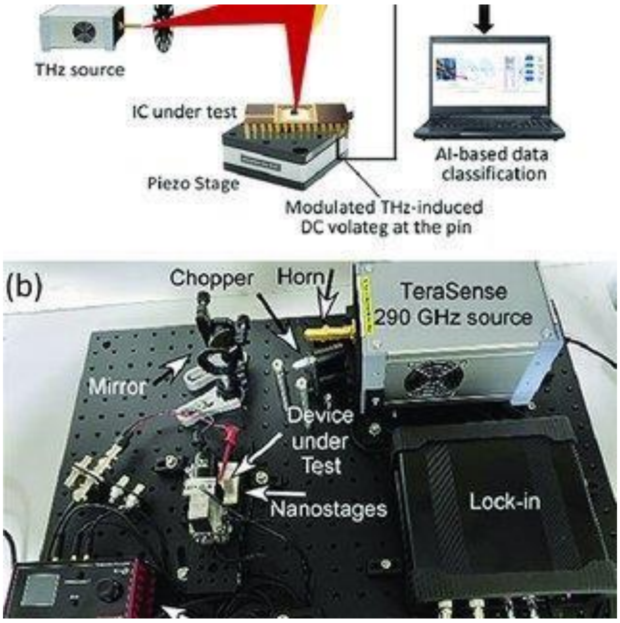

Fig : Terahertz testing Setup

LITERATURE SURVEY

Terahertz (THz) technology is a rapidly advancing field. IC complexity can be separated by its interconnect type and feature size. Some examples are flip-chip, wirebond, wafer- level packaging (WLP), and through-silicon vias (TSVs) which comprise many of the connections from the macroscale flip-chip IC to PCB connections down to the nanoscale transistor and die connections. A modification or defect at any of these levels can cause device mis-operation, data leakage, or premature failure of an IC during its life cycle. This failed IC can cause compromise or enable malfunction of interconnected systems such as the assembled PCB device dueto the prematurely failed IC.

IC integration scales from small- to very large-scale integration, referring to the number of components per chip. As the number of connections increases, and approaches VVLSI, with more than 1 million components per chip, this has required higher spatial resolution and faster techniques to meet the high-volume requirements of the electronics industry. THz IC characterization can be segmented into counterfeit detection and defect detection and localization. THz defect localization has been used to mitigate nano- or micro-sized defects in the VLSI design, while counterfeit detection has focused on micro- and macro differences in the IC die, epoxy molding, or pins. A beginner's level introduction to IC packaging has been compiled by Lancaster and Keswani, while FA techniques for 3D packaging were reviewed by Altmann and Petzold, Li et al., and De Wolf et al. Interconnect quality and reliability for 3D IC packages were reviewed as part of Springer's "Series in Advanced Microelectronics" book covering microstructure changes and failures driven by mechanical, electro, and thermal stresses, which are important as many modern mobile devices fail due to high frequency impacts with the ground.

The use of THz radiation to form images has been used for IC packaging inspection since 1995. The packaging materials of the ICs are compositions of different materials, and these materials are transparent to the laser in the THz region. By recording the reflected or transmitted beams in certain step intervals and mapping the reflected or transmitted beams on a 2D plane, analyzing an entire layer is possible on one graph. THz-TDS systems can record the intensity and time delay of the traversed THz pulse and generate the THz images

Ahi et al. [6] used THz-TDS methods combined with PSF- based image restoration techniques to characterize and identify quality control issues that can be used for authentication of packaged ICs below the diffraction limit of the THz wavelength. This method was able to detect the presence of unexpected materials in counterfeit devices, blacktopping layers (used by counterfeiters to hide the original label and overprint a false one), shape and dimensions of hidden structures, sanded and contaminated devices, differences between internal structures of counterfeit and authentic devices, such as misshapen die-frames and bond- wires.

The resolution enhancement for THz imaging is critical for THz techniques where 3D reconstruction is performed on THz data. In 2020, Li et al. [8] resolution enhancement has been combined with machine learning. This is accomplished by integrating the focused THz beam distribution, which determines the relationship between the imaging range shape and dimensions of hidden structures, sanded and contaminated devices, differences between internal structures of counterfeitand authentic devices, such as misshapen die-frames and bond-wires.

METHODOLOGY

In this work, the terahertz response of ICs as signature data has been used to classify secured and unsecured/faulty ICs. The DC response on a selected pin of radio frequency integrated circuits (RFIC) is measured while scanning a focused terahertz beam on it to obtain a 2D signature response map. Resolution of this technique is in the nanometer range, even though the radiation wavelength is hundreds of micrometers. By applying data augmentation processes, a secure image data set has been created to train the convolutional neural network (CNN) models.

The data augmentation method has also been used by adding randomized noise in the authentic response data and produced randomized response data. All response data has been further divided into two categories:

Secure response set and unsecure response set and then these data sets have been fed into the designed CNN model. The data augmentation method has also been used by addingrandomized noise in the authentic response data and producedrandomized response

The classified images are distinguished with accurate prediction based process. A graphical user interface (GUI) has also been designed using the MATLAB App Designer forend-users to train CNN with new data and identify ICs easily.

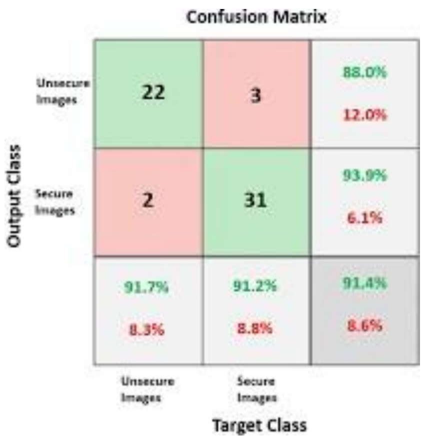

Fig :Confusion Matrix

The DC response on a selected pin of radio frequency integrated circuits (RFIC) is measured while scanning a focused terahertz beam on it to obtain a 2D signature response map. Resolution of this technique is in the nanometer range, even though the radiation wavelength is hundreds of micrometers. By applying data augmentation processes, a secure image data set has been created to train the convolutional neural network (CNN) models. unsecure response set and then these data sets have been fed into the designed CNN model. The classified images are distinguished with accurate prediction based process. A graphical user interface (GUI) has also been designed using the MATLAB App Designer for end-users to train CNN withnew data and identify ICs easily.

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TERAHERTZ RESPONSE BASEDIC TESTING

The proposed method is based on the fact that a modern field effect transistor (FET) with a sufficiently short channel can serve as a terahertz detector. This detection process has a sub wavelength resolution. The impinging terahertz radiation on a transistor couples through the contacts or interconnects and excites the over-damped or resonant plasma waves, i.e., the waves of the electron density in the device channel. The rectified response due to the transistor nonlinearities results in an induced DC voltage on the I/O pins. A lockin amplifier is used to measure and record the frequency modulated response. The IC can be placed on a nano-stage, and the induced DC response can be scanned by moving the IC in 3D (x, y, and z) under the impinging terahertz radiation.

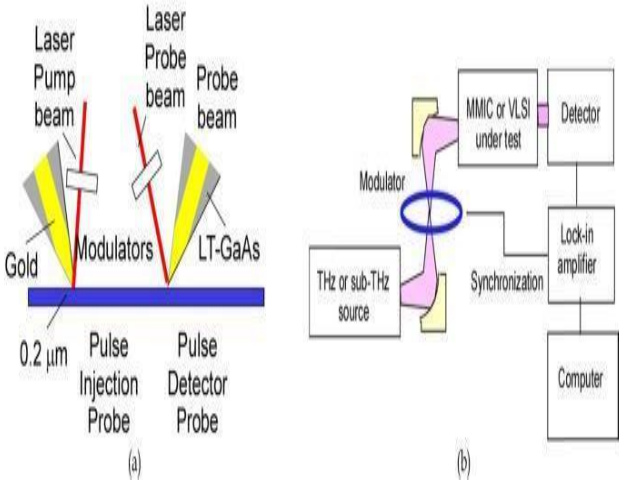

Fig: Sub terahertz testing

The resulting spatial dependence of the response depends on the collective response of all the FETs in the IC and forms a unique signature that could be used to differentiate genuine/healthy ICs from forged/defective ones. Automated scanning and AI analysis is used to demonstrate a proof-of- concept platform for fast and accurate IC testing. Fig. 3.1(a) shows the schematic description of the terahertz IC testing method used here. A significant advantage of this new non- invasive and nondestructive technique compared to other radiation enhanced testing methods is that this approach does not affect the device

The classified images are distinguished with accurate prediction based process. A graphical user interface (GUI) has also been designed using the MATLAB App Designer for end- users to train CNN with new data and identify ICs easily operation and could work with no bias or under bias. In contrast to the conventional terahertz imaging, this technique can use the intensity, polarization, frequency, and bias dependencies of the terahertz response at the VLSI or MMIC pins for a more detailed IC response. It can also find applications as a testing technique for Si and compound semiconductor devices and circuits for defect identification, reliability prediction, and fabrication process optimization. systems remains much higher than any initial classical states can provide. This implies that the use of entanglement should not be dismissed in entanglement-breaking scenarios.Quantum illumination takes advantage of this stronger.

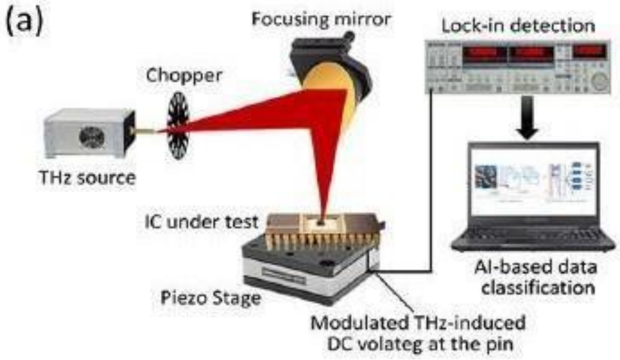

Fig **:** Schematic presentation of the terahertz scanningsetup for generating spatial terahertz response map forAI based image processing**.**

IMPLEMENTATION

TERAHERTZ IC SCANNING SYSTEMS

For the experimental data acquisition, a fixed frequency IMPATT diode-based terahertz source operating at 0.289 THz with an 8.5 mW output power and with 26dB gain detachable horn antenna was used. This setup is shown in Fig.

4.1.1. The samples that were wire-bonded on the chip carriers placed on three-axis nano-stages controlled with a computer connected KIM101 controller and had the steps down to 5 µm. The Stanford Research SR830 DSP lockin- amplifier measured the response with an optical chopper. Custom LabView codes performed all the equipment control and data acquisition. The samples that were wire-bonded on the chip carriers placed on three-axis nano-stages controlled with a computer connected KIM101 controller and had the steps down to 5 µm. The Stanford Research SR830 DSP lockin- amplifier measured the response with an optical chopper. Custom LabView codes performed all the equipment control and data acquisition.

. The whole CNN consists of two categories: i) Feature learning and ii) classification. The feature learning section consists of convolutional layers, ReLU layers, and pooling layers and the classification section two max-pooling layers, one fully connected layer, one SoftMax, and one classification layer were selected. CNN is the best method fordata classification in deep learning neural networks inspired by the visual cortex layout.

DEEP LEARNING - CONVOLUTIONNEURAL NETWORK (CNN)

To design the CNN model, one image input layer, three convolution 2D layers, two batch normalization layers, three rectified linear unit (ReLU) layers, two max-pooling layers, one fully connected layer, one SoftMax, and one classification layer were selected. CNN is the best method for data classification in deep learning neural networks inspired by the visual cortex layout. Fig.4.2.1 shows the basic convolutional neural network model that has been used for image classification. The whole CNN consists of two categories: i) Feature learning and ii) classification. The feature learning section consists of convolutional layers, ReLU layers, and pooling layers and the classification section

CONCLUSION

In conclusion, a novel terahertz AI testing method for non- destructive and unobtrusive identification and classification of genuine ICs and counterfeit, damaged, or forged ICs was successfully demonstrated. This applied approach is based on measuring the IC response to terahertz and sub terahertz radiation at the circuit pins. Measuring at a larger number of pins under different frequencies and polarizations of terahertz radiation can produce more complex terahertz response signatures, which would result in higher classification accuracy. This approach does not affect the IC operation and could provide detailed IC signatures.

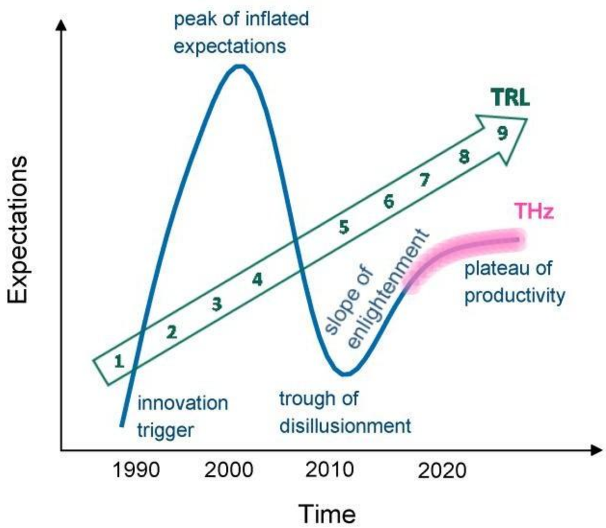

Fig : Terahertz Sensing

The classification process between the secure and unsecure IC images was explained using the convolution neural network with ~86 to 94% accuracy and its graphical user interface. This accuracy level can be further improved by using transfer learning to suppress any data over fitting issues. Terahertz signatures of the individual ICs can be generated by applyingdifferent measurement processes under different polarization,frequency, and depth of focus.

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This applied approach is based on measuring the IC response to terahertz and sub terahertz radiation at the circuit pins. Measuring at a larger number of pins under different frequencies and polarizations of terahertz radiation can produce more complex terahertz response

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