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Terahertz Technology with AI-Powered Expert-System for Ensuring Hardware Security & the Reliability in Monolithic and Bilithic VLSI Chips for Bio-Medical Image Processing Applications

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Abstract: In this paper, we provide a concise overview of a novel approach that combines Terahertz technology with an AI dependent expert system to safeguard the hardware securities & the reliabilities of monolithic and bilithic VLSI based IC chips. Ensuring the securities of hardware components has become a critical concern, particularly for intricate integrated circuits. Defective integrated circuits pose a significant threat to system security and dependability. With the growing complexity of digital signal systems, the task of developing effective methods for analyzing and authenticating the trustworthiness and legitimacy of integrated circuits has become more challenging yet indispensable. We propose a new terahertz-based inspection process for non-destructive and subtle identification of counterfeit or malfunctioning integrated circuits. This process involves sensing the response of the circuit to incident terahertz radiation and analyzing this response using artificial intelligence techniques. Terahertz technology is employed for its ability to provide a unique fingerprint feature that can distinguish between genuine and counterfeit integrated circuits. To facilitate the training of the convolutional neural network (CNN) model, a secure image dataset is created using data augmentation techniques. Additionally, an insecure image dataset is generated by modifying the original image data to represent altered integrated circuits. Remarkably, the trained models achieved a success rate of 90% in correctly identifying secure devices..
Keyword: VLSI, Hardware, System, Terahertz, IC, Chips, CNN, Artificial Intelligence, Monolithic, Deep Learning.

1. Introduction Remarks

With the increasing complexity of systems, particularly integrated circuits, these systems have become more vulnerable to a wide range of security threats. Integrated circuits (ICs), due to their immense sophistication, can be inadvertently altered at various stages of their lifecycle, including design, manufacturing, or packaging. This can occur for a variety of reasons, such as material degradation, equipment failures, or unpredictable external factors. Furthermore, the possibility of counterfeit ICs entering the supply chain poses a significant risk, potentially disrupting legal frameworks and structural integrity during their deployment. Counterfeit chips, often equipped with additional hidden functionalities, are increasingly becoming commonplace in critical components and machinery. This raises significant concerns about hardware security, especially as the use of custom-built external hardware is on the rise [1] [44].

Furthermore, with the rapid aging of widely deployed cyber infrastructure, it is imperative to establish precautions and response strategies to address all hardware security threats effectively, thus preventing potential disasters and irreversible consequences. Compromised or untrustworthy integrated circuits (ICs) can pose significant risks to the entire global cyber network infrastructure, with severe and extensive repercussions. Traditional AC and DC electrical testing methods often fall short in providing comprehensive problem identification, and counterfeit circuits, designed to evade conventional testing techniques, introduce additional security concerns [2] [44].

To distinguish counterfeit ICs from genuine ones, there is a need for simple, thorough, non-destructive, and widely adopted inspection and testing methods. The IC packaging industry has developed several non-destructive testing techniques since the 1970s. These techniques include X-ray, infrared thermography (IRT), surface acoustic waves (SAW), and terahertz transmission and reflection imaging, all of which are non-invasive methods for examining integrated chips. Terahertz imaging, in particular, offers an excellent approach for detecting anomalies since many materials exhibit distinctive features in the terahertz spectrum. Despite the vast potential of terahertz imaging systems, their inherent limitation in terms of low-resolution imaging poses challenges in convincing the industrial sector to adopt them as a practical tool for advanced algorithmic design automation circuits, especially as characteristic sizes continue to shrink to 7 nm, 5 nm, and even 3 nm [3] [44].

Rather than relying on ultra-wideband imaging technology, a novel approach to terahertz inspection of monolithic microwave integrated circuits (MMICs) and very large scale integrated circuits involves evaluating the circuits' direct current bias responses at the pin and input-output connections. These responses are subsequently analyzed using a Fabry-Perot interferometer. Even minor alterations in the semiconductor's reactivity can have a significant impact on the effectiveness of this method. The tremendous potential of terahertz technology within the chip's boundaries can serve as a diagnostic tool for detecting irregularities and deviations in the desired output. This approach has the capability to predict the longevity and reliability of the circuits by identifying and diagnosing potential issues [4] [44]..

2. Testing Process IN Real Time Environment

Various inspection systems are currently in use to detect and differentiate counterfeit components. These procedures are employed to identify defects in a single component or a batch of components. Counterfeit integrated chip components may exhibit a range of anomalies or deviations from the behavior of a genuine part. These anomalies could be of a physical nature, such as those related to leads or packaging, electrical in nature, or they could be intentional alterations [5] [44].

2.1 Analyzing Of The Process Involved

Genuine and counterfeit ICs often have distinct packaging. The refractive index of the packaging material has a significant impact on the range of strong refractive indices. Terahertz time-domain spectroscopy (THz-TDS) equipment is used to record and differentiate the depth and duration of transverse terahertz pulses emitted by authentic and counterfeit or malfunctioning chips. Due to variations in their refractive indices, fake ICs exhibit differences in the time delay and attenuation of their transverse terahertz pulses compared to genuine chips. Counterfeit integrated chips can be readily identified due to the differing time delays corresponding to layer thicknesses within integrated electronics [6] [44]

In the case of incoming radio frequency waves, each pin on an IC receives distinct frequency-structured dispersion responses. These dispersed frequency-structured responses are harnessed to represent a single chip as a unique fingerprint with a high degree of consistency. The physics governing this process determines the initiation of the entry impedance at external nodes. Impedance, being a frequency and phase-dependent characteristic within the circuit, arises from the complex interconnection properties at radio frequencies and higher frequencies. The parameters within the IC package are critical in defining these frequencies and structure-based fingerprints. This impedance-based comprehensive approach is both repeatable and non-invasive, allowing for the discrimination between counterfeit and authentic ICs [44] [7].

2.2 Imaging Process For Testing Using X-Rays

The three-dimensional configuration of a contemporary microprocessor can be non-destructively reconstructed using the computational approach of microscopic imaging X-ray laminography. This method can expedite the process, particularly in light of the extensive semiconductor-related coverage. The existing technique for manufacturing ICs without causing damage is instrumental in ensuring adherence to cutting-edge concepts in device production. The X-ray computational approach to microscopic imaging is applicable to un-thinned chips, even those as thick as 240 micrometers, offering imaging capabilities at a 20-nanometer resolution. This enables inspections without encountering the constraints associated with thinning, such as fragility and heat generation [44] [8].

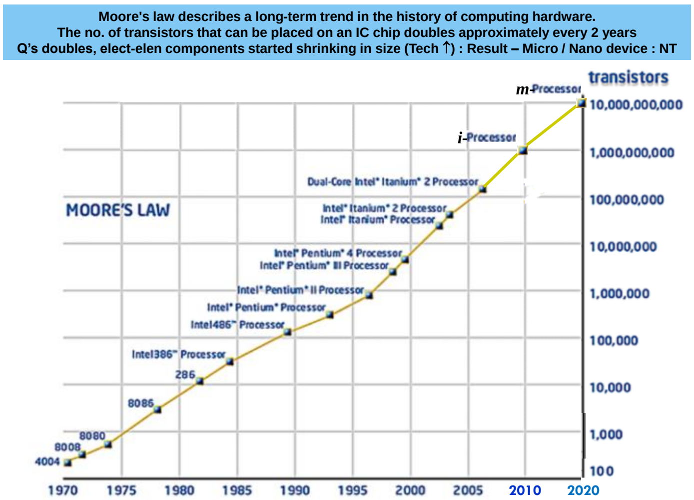

Fig. 1: Visual Representation of Gordon Moore's Law

3. Novel FET Conduits

By employing a novel field-effect transistor (FET) and a suitably fast conduit, a terahertz detector can be constructed, offering subwavelength sensitivity. This detection method capitalizes on the phenomenon known as the resonance liquid effect, which arises when terahertz radiation infiltrates a field-effect transistor and couples across its contacts. The nonlinear effects within the transistor yield an adjusted response in the form of an induced potential at the input-output pins [9]. The Fig. 1 gives the graphical representation of the Gordon Moore's law [44].

To measure and record the frequency-modulated response, a lock-in amplifier is utilized. The chip, when positioned on a nanoscale stage, can be subjected to terahertz radiation from various angles, allowing for the observation of the triggered direct current response in three dimensions. While very-large-scale integration (VLSI) testing is a practical necessity, features that enhance testability must be managed carefully to avoid compromising system security. Security breaches in testing procedures could potentially jeopardize data confidentiality and the protection of intellectual property. This paper delves into the examination of security concerns in testing, with a specific focus on the scan technique [44] [10].

The semiconductor industry has been exploring the utility of terahertz (THz) signals for inspection and fault detection since their initial generation and detection. However, THz systems lacked the signal quality and reliability required for effective non-destructive testing (NDT) until recent hardware advancements. Thanks to incremental developments in THz sources, detectors, and signal processing, THz NDT techniques have now been successfully employed in assessing carbon fiber laminates, automotive coatings, and the authentication of pharmaceutical tablets to combat counterfeiting. For various critical industries, semiconductor inspection and verification procedures are paramount for ensuring the functionality and safety of essential devices. Therefore, the reliability and effectiveness of THz NDT methods must surpass current inspection technologies [12] [44]. Experimental Procedures Development

The unique signature that can be used to differentiate genuine from counterfeit integrated circuits stems from the collective response of each transistor within the chip, which in turn determines the reultant dimensional dependence of the reaction. While the method outlined in the sources is commendable, it may not be the most optimal choice for more efficient and complex chip inspection. The current groundbreaking non-invasive and non-destructive technology offers a significant advantage over alternative emission-assisted inspection techniques in that it does not impact the operation of the device. In contrast to traditional terahertz imaging, this approach leverages the brightness, polarization, repetition, and bias effects of terahertz radiation on very-large-scale integration (VLSI) or monolithic microwave integrated circuit (MMIC) pins to yield a substantially more distinctive chip response [11] [44].

Moreover, this method can find application in inspecting silicon-based complex circuitry tools, such as integrated circuits, and also serve in the detection of anomalies, the prediction of durability, and the enhancement of fabrication processes. For terahertz radiation generation, a fixed-frequency IMPATT diode at 0.289 THz was utilized, delivering an output power of 8.5 mW and paired with a 26dB beneficial detachable horn projection. The wire-bonded samples were meticulously positioned on three nano-ranges, finely controlled by the laptop-connected KIM101 controller, with stage increments as minute as five micrometers. The Fig. 2 gives the pictorial representation of the developed steganographic models of the proposed steganographic system [44].

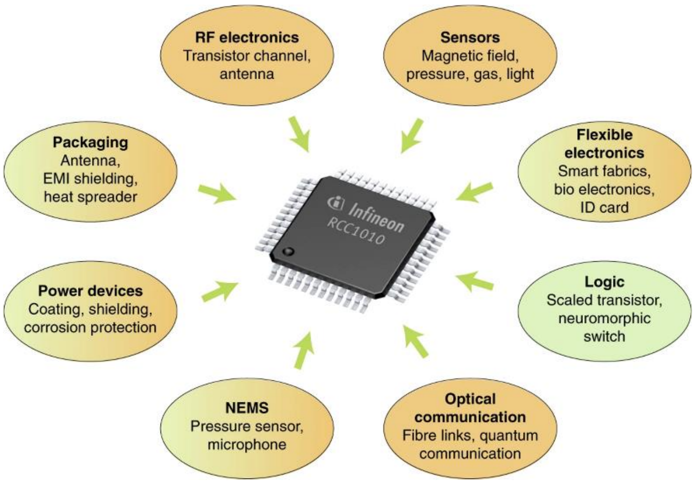

Fig. 2: Visual Representation of the Developed Steganographic Models in the Proposed Steganographic based System [12] [13]

4. Convolutional Neural Networks (CNN's)

The configuration of the CNN version consisted of a single image input layer, three 2D convolution layers, group normalization layers, three rectified linear unit (ReLU) layers, max-pooling layers, a fully connected layer, a SoftMax layer, and a classification layer. In deep learning neural networks, the most effective method for data categorization is the convolutional neural network (CNN), inspired by the visual cortex's functioning. The entire CNN comprises two key components: I) feature learning, and II) classification. Feature learning involves convolutional layers, ReLU layers, and pooling layers, while classification employs fully connected layers and the SoftMax activation function. The convolution layer components consist of the convolution process, activation functions, feature maps, and activation maps [44].

The CNN algorithm excels at extracting intricate features from input images, such as edges. To capture basic features like edges, color, and gradient orientation, only one convolution layer is typically needed. The network then responds to high-level features and comprehensively understands the dataset's images through the provided layers and filters. For activation functions, CNN utilizes ReLU, sigmoid, and tanh, depending on the specific application. Among these, ReLU is the most widely used activation function in neural networks, especially in CNNs, for enhancing non-linearities [44].

The range of the resulting distinctive pattern matches that of the CNN filter, and the output of the transformed distinctive pattern is less than that of the original image. A unique rate can be employed to adjust a feature detector to generate distinctive results, whether enhancing and customizing an image or concealing one. The primary purpose of the pooling layer is to reduce the dimensional size of the convoluted features, thus decreasing the computational time required for analysis. Once the pooling layer is applied to the distinctive map, it produces a pooled feature map. Data can be pooled using either the Max Pooling or Mean Pooling methods. Max

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Pooling selects the maximum value, while Mean Pooling calculates the average of all values.. The Fig. 3 gives the structure of how macrro to nanotechnology took place [44].

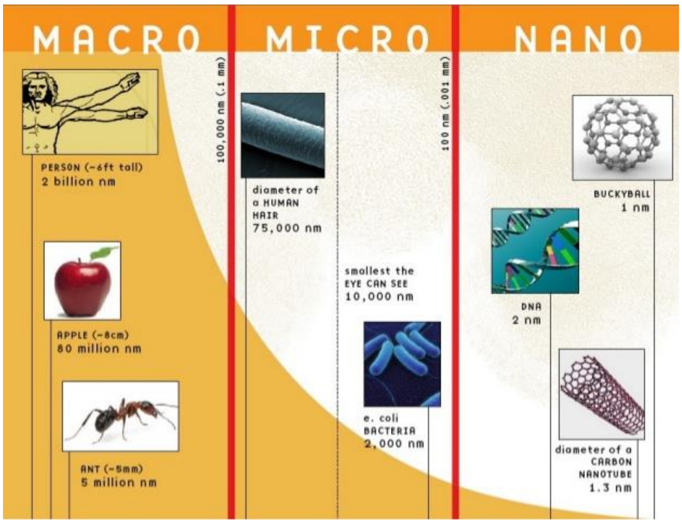

Fig. 3: Structure of how macrro to nanot took place

The primary objective of feature extraction elements is to identify properties and encode them into the feature map while preserving the dimensional relationships of the pixels. All the various layers that were initially added would be condensed into a vector, and the categories would be represented through pooling in a single sheet. Using the SoftMax activation operators, this layer would convert the output into the desired set of categories across the network; in this case, the categories are both secure and insecure. The CNN model trained the images using forward and backward propagation over several epochs [44].

Terahertz (THz) radiation can be utilized to simultaneously assess structural characteristics, THz electrical signatures, and chemical data. THz non-destructive testing (NDT) semiconductor inspection technologies faced limitations in transitioning from laboratory settings to the dynamic environment of semiconductor manufacturing due to cost and environmental constraints. THz spectral and structural data can be combined with established methods like optical, X-ray, or E-beam in hybrid metrology approaches that integrate information from multiple inspection tools. THz can address the extensive failure analysis and verification requirements of the semiconductor industry, covering features from the nanoscale to macroscale [12] [44]..

5. Some more review results

The observed response is a result of scanning a tightly focused terahertz beam across the semiconductor. This approach is employed to generate the terahertz response signature of an integrated circuit (IC). For the classification study, a 3-D nano-stage was utilized to capture 2D measurement scans. The scanned terahertz beam was precisely centered on the IC and traversed twenty-five steps in the coordinate axes. The response was measured under the same biasing conditions in the chosen configuration of the identical instrument. The outcomes of the two consecutive scans are presented in images 1 and 2, highlighting the method's repeatability. The height of the tool holder was adjusted for each experiment, resulting in photos three through six [44].

The specific focal point in the vertical direction leads to variations in the computed scans from two to six. This approach allowed for consistent image capture while taking into account the precise vertical position of the scanning beam. The differences observed in scans 2 to 6 can be attributed to distinct vertical focus settings. This method enables the acquisition of reliable images while considering accurate vertical scanning beam placements. When measuring the responses of different pins, a distinct 2D response map can be generated for each pin, offering valuable insights, particularly in complex Very Large Scale Integration (VLSI) circuits with numerous transistors [44]..

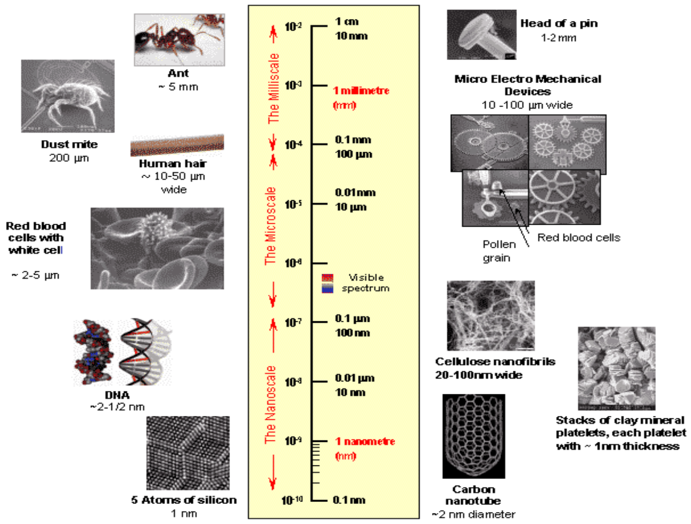

Fig. 4: Different sizes of nano particles

To establish THz systems as independent inspection tools for monitoring semiconductor production, there is a substantial need for high-level statistical process control in THz signal generation, detection, and processing. The realization of effective industrial semiconductor device inspection is likely to result from a combination of advancements in THz hardware, reconstruction techniques, and the widespread application of machine learning methods. Over the years, various breakthroughs have enabled the successful nondestructive characterization and inspection of semiconductor devices, ranging from nanoscale transistors to densely packed integrated circuits and fully assembled printed circuit boards [12]. The Fig. 4 gives the different sizes of nano particles [44].

Our AI methodology is currently undergoing generalization for advanced Very Large Scale Integration (VLSI) applications, with further details to be provided in subsequent discussions. Valid or stable image snapshots are derived from the statistical data collected and smoothed into 100 × 100-pixel units. The consistency observed in the data obtained through successive scans indicates that the measurements are repeatable, with the exception of snapshots three and four. Notably, a dimensional setting error was identified as the cause of the distortion observed in image three. The Fig. 5 gives the evolution of how the technologies took place in the modern digital world [44].

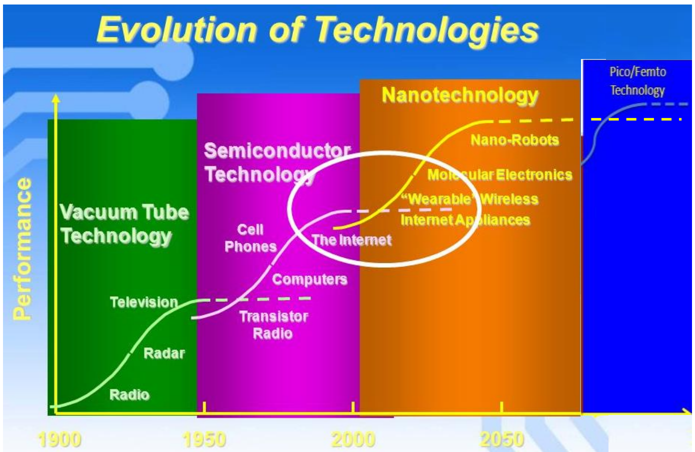

Fig. 5: Evolution of how the technolgies took place

The initial 60% of the document devices were categorized into two classes: secure and insecure, for the purpose of CNN training, while the remaining 40% were reserved for evaluating the trained CNN. During a single epoch, all of the training samples undergo the same set of rules before any weight adjustments are made. After each instruction vector is executed sequentially in the training rule set, all assigned weights are updated for iterative training. However, within the training framework, the training may be inadequate for a limited number of epochs, which can result in underfitting. On the other hand, if the model is excessively trained, it may memorize the expected outputs for the training inputs, leading to overfitting. To ensure practical applicability, we have chosen a maximum of 60 epochs for the first 60% of the data and 40 epochs for the remaining 40%, considering their real-time processing constraints [44]..

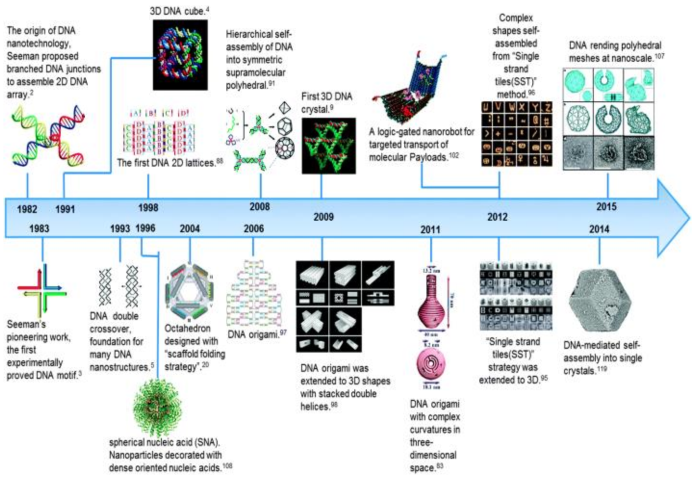

Fig. 6: Decade-wise improvement in the real time hardware development process

Counterfeit electronics are a big problem because the supply chain for electronic components has become more complicated. These components come from various sources, making it hard to ensure they are genuine. Right now, there aren't many rules and methods to detect fake parts. Counterfeit components can be recycled, modified, made in excess, copied, not up to standards, or come with fake documents. Even if they seem to work at first, these parts may not last long and could fail, which is risky. So, we need a better way to check them. The Fig. 6 gives the decade-wise improvement in the real time hardware development process [44].

To solve this problem, we need a more reliable and effective method than what we currently have. People often compare terahertz (THz) inspection methods to other ways of checking electronics, like using light, electricity, and measurements, to see if THz methods are good for making and checking electronic parts. These THz methods work well for checking printed circuit boards, integrated circuits, and transistors. They can even pass through materials like plastic, ceramics, and semiconductors because their wavelength is in between optical and electronic ranges. This makes them very useful for ensuring the quality and reliability of electronic components [44].

6. Conclusions

In this research paper, the authors introduced a system that uses Terahertz and AI technologies to protect the security and reliability of very large integrated chips. They developed a non-intrusive terahertz AI testing method to distinguish between genuine and fake or defective ICs. This method relies on the IC's response to terahertz and subterahertz emissions at multiple pins, improving the accuracy of the results. The approach doesn't affect the IC's functionality and provides precise information. To classify IC photos as secure or insecure, the researchers used a convolutional neural network with an accuracy rate between 86 and 94 percent, along with a graphical user interface (GUI). This level of accuracy can be further enhanced.

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