Reliability Analysis and Counterfeit Detection in Integrated Circuits Using Thermal Imaging

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Abstract—Integrated circuits (ICs) are an integral part of the modern electronics industry. In turn, counterfeiting these chips has become an illegitimate way to save money and maintain high profits. As counterfeit chips are much less reliable than their authentic counterparts, serious harm (to both devices and their users) can come out of using them. The process of thermal imaging can be used to detect counterfeiting in ICs. By examining the silicon dies of a chip with a thermal infrared camera, colored or grayscale temperature maps of the device can be obtained. These (analog) maps can be discredited using Fourier analysis, then compared to those of other chips. From this, statistical outlier analysis can be used to determine which chips are out of the ordinary.

I. INTRODUCTION

As integrated circuits are used in most of today’s technologies, their cost and effectiveness play an important role in the fabrication of devices. Due to the importance of cost, the problem of counterfeiting chips has risen over the past few decades. Today, counterfeiting is a billion-dollar industry that relies on outsourcing manual labor to third-world countries. There are many different types of counterfeiting, but the most prevalent (and most problematic) is recycling of ICs. In fact, 80% of all counterfeit chips are recycled. Around the world, electronic devices containing valuable parts are discarded. Many of these unusable devices are sent to developing countries, where the useful ICs are taken off and resold into the market (at a much cheaper price than new ICs). This whole process causes already unreliable chips to become even more unstable. While cost-effective, the negative impacts of recycling ICs greatly outweigh the benefits.

II. PROBLEM

The major problem that arises when dealing with counterfeit ICs is the fact that companies cannot be sure, just by looking at a device, whether or not recycled ICs were used in its fabrication. Using a counterfeit IC can lead to dysfunctionality, breaking, or a shorter lifespan of the product. In turn, this can give a bad reputation to the company, or even cause injuries (if a product breaks in a critical application). To first understand this problem, one needs to first understand why ICs are damaging as they are aged. The theory behind this comes from the fact that, in an IC, aging causes AND is caused by increased power consumption. In other words, if a chip is old, it will consume more power. And, if a chip is consuming more power than it normally does, it will age faster. This increased consumption of power for an elongated period of time is what causes chips to break. This can be a serious problem in critical applications, especially when the device that is using the aged chip is in a position where it cannot be fixed. For example, if a counterfeit chip was used in the inertial measurement unit of a lunar rover, and the chip breaks, no one would be able to replace the part. In this situation, the engineers would want to be 100% sure that they are using the most reliable chip. Using a recycled IC may cause the rover to break after one week of use, when it was supposed to be deployed for years. In this project, the reliability of a chip will also be examined. The term “reliability” is a qualitative measurement based on the integrated performance of the different components within the chip. Obviously, a counterfeit chip is much less reliable than an authentic chip, so the two issues go hand in hand. Part of the problem, however, will be to create a system of determining exactly how reliable an IC is.

III. SOLUTION

A. Temperature and Power Consumption

The key to solving the problem of counterfeit detection is measuring the temperature of ICs. As stated before, the power consumption rate of a chip is affected by its age, meaning that power consumption is a good indicator as to whether or not a chip is counterfeit. The relationship between power consumption (in the form of heat) and temperature is given by the heat diffusion equation (Eq. 1) [1].

$$\nabla \cdot [k(x,y)\nabla t(x,y)] - ht(x,y) = -p(x,y)$$

(1)

In this equation, $k$ is the thermal conductivity of the device at point $(x, y)$, $t$ is its temperature, and $p$ is its power consumption. The value $h$ represents the heat transfer coefficient. Although complicated, this Equation 1 basically states that the operating temperature of a device plays a major role in the amount of power consumed. This is a mutual relationship, so when power consumption is increased, the operating temperature is also increased (in the areas with increased power consumption). Figure 1 demonstrates this phenomenon and
leads us to the next, and most important part of the solution: thermal imaging.

![Increasing Power](image)

Fig. 1. Temperature of an IC as power consumption is increased. It should be noted that this is just an example of the theory, and was not the result of an actual experiment.

B. Thermal Imaging, Decapping

A thermal camera can be used to take pictures (like Fig. 1) of a chip’s die, or the small silicon piece at the center of an IC. These pictures can be analyzed through Fourier analysis to give the heat signature of the chip. The technical process behind this is fairly complex, but will be completed by using computer software and applications. There are some obstacles that must be resolved before any type of thermal imaging can be done. First, a chip cannot be thermally analyzed before it is decapped. This means that the plastic covering of the IC must be removed, revealing the die, as shown in Figure 2. This must be done because the chip’s plastic covering dissipates heat, and any thermal image of a capped chip will be skewed.

![Decapped Chip](image)

Fig. 2. An example of a decapped chip.

An additional problem is that not all chips are fabricated with the silicon die facing upward. Some chips will need to have their pins flipped upside-down (after being programmed) and then decapped from the bottom.

C. Programming and Burn-In

Once these processes are verified (to see if the IC works properly upon completion), a few chips will need to be programmed. In this project, 8051 microprocessors will be used as the test chips because they are cheap and have the most basic chip components. These programs will stress different parts of the IC, such as the arithmetic logic unit (ALU) and the memory caches. The thermal imager will then examine the chip when it is operating under those programs to see if the heat increases in the corresponding components. However, to be able to compare counterfeit chips to authentic chips, we first need to have a burned-in IC. Burn-in is a process that simulates aging in a chip, and is accomplished by heating the chip for a long period of time (when it is running a program). The acceleration of age from the burn-in process is given in Eq. 2, where the $T$ values are temperatures, and ‘$E$’ and ‘$k$’ are constants.

$$A_T = \exp \left[ \frac{E_a}{k} \left( \frac{1}{T_{use}} - \frac{1}{T_{stress}} \right) \right]$$ (2)

D. Analysis

The final part of our solution is to compare the heat signatures of different chips. We will first use an outlier analysis method to determine which chips are out of the ordinary. The burned-in chips should be part of this group. Then, when we have an “average” heat signature that represents a completely authentic chip, we will use a method called golden IC analysis to compare each chip that is thermally imaged to that signature. Again, these processes will involve extensive statistical analysis that can be completed through the use of computer applications.

IV. Timeline

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V. Budget

The budget for our project is fairly simple. We were given $5,000 in hopes of buying a thermal infrared camera (for imaging). However, as the cheapest thermal camera we could find costs around $20,000, we will explore other options like renting a camera or travelling to an off-campus site. The money will be used to purchase the chips (8051s, which are not
expensive) and possible mounting equipment or circuit boards. If we rent a camera, we may have to purchase a desirable lens (for focusing) that could cost around $2,000.

VI. REFERENCES