Catastrophic Die Detachment: The Dominant Failure Mode of Pentium® Keychains

David Harris
Stanford University
Stanford, CA

Introduction

The Intel Pentium® Processor Keychain is a popular item in the burgeoning silicon jewelry market. It has the potential to become the fastest-growing segment of Intel Corporation’s world-wide sales, especially when yields are aggressively optimized. The author has conducted a thorough failure analysis on the keychain and has determined that catastrophic die detachment is the dominant failure mode seen by the end user.

Manufacturing Overview

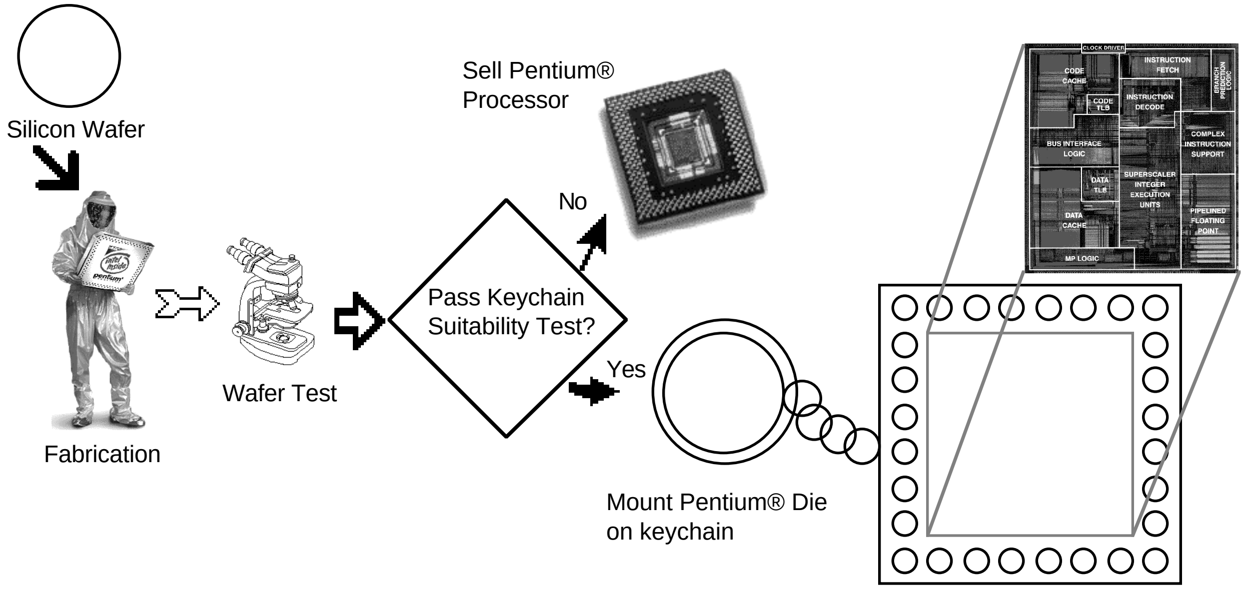
The Pentium® processor Key Chain is a byproduct of the standard, high-volume Pentium® processor manufacturing process. Figure 1 illustrates the manufacturing steps. First, a pure 8” silicon wafer undergoes epitaxy, ion implantation, diffusion, and 3 or more levels of metalization in a multi-billion dollar BiCMOS fabrication facility. Contaminants such as dust particles are introduced by sneezing on the wafer during manufacturing. As part of wafer sort, a Keychain Suitability Test is performed on each Pentium® processor die. Dice containing contaminants pass the test and continue through the keychain manufacturing flow. Dice which fail are mounted in packages and sold to computer system vendors.

Suitable dice are manually aligned in a low-cost 167 pin metal PGA package and are secured to the package with a dot of adhesive. A thin epoxy layer passivates the surface. A key ring is mechanically affixed to the package and the finished product is shipped to market.

Economic Issues

Pentium® processor Key Chains are sold in retail outlets for $8.99. This aggressive pricing (compared to $200--$1000 for dice which fail the Keychain Suitability Test)

Figure 1: Pentium Keychain Manufacturing Process



makes the items particularly attractive to end users who wish to own a Pentium® processor but must live within a tight budget. In particular, explosive product growth is forecast in China so long as trade negotiations proceed well.

To analyze the profit margin on Pentium® processor keychains, we must understand the manufacturing cost. Manufacturing cost depends strongly on die area. Large dice make attractive keychains but not many fit on a wafer. In general, we would like to maximize the number of keychains N times a weighted factor of the keychain area A: $N \bullet A^k$ for some weight $0<k<1$. If we assume a uniform defect density of ρ (defects/cm^2), we can solve for the optimal die area. The probability a die passes the Keychain Suitability Test is found from the Poisson process to be $1-e^{-\rho A}$. Therefore, we want to maximize the expression:

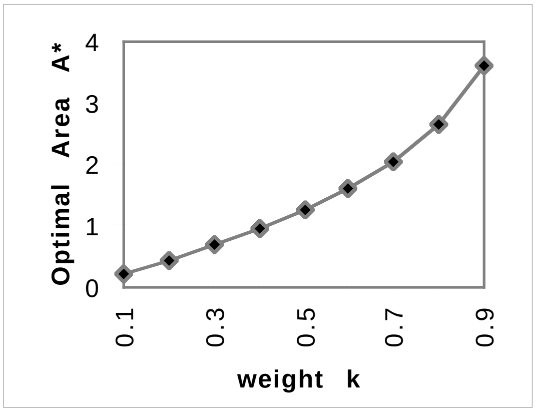
$$A^{k-1}(1-e^{-\rho A})$$

Differentiating and setting the result to 0, we find an implicit expression for the optimal A^*:

$$A^* = \frac{1}{\rho}\ln\frac{\rho A^* + (1-k)}{1-k}$$

Figure 2 shows the optimal area as a function of weight k for ρ = 1defect/cm^2:

Figure 2: Optimal Die Area



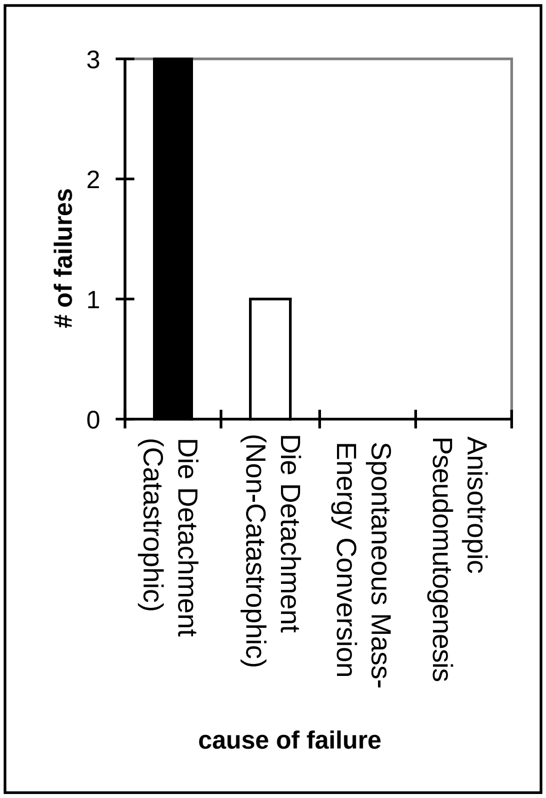
When a process is new, ρ is high and many good keychains may be produced. As a process matures, ρ decreases and fewer keychains are available. Eventually, Intel is forced to migrate to a more advanced process with higher ρ in order to meet keychain demand.

Failure Analysis

Product quality and reliability is an essential concern of any manufacturing organization. Although burn-in using mechanical vibration at elevated temperature can weed out a fraction of defective Pentium® processor keychains, extensive field testing is necessary to understand the failure modes seen by end users. This author conducted a study of keychain failure. The study was performed by affixing seven keys and a small pocket knife to the keychain, then transporting the keychain in the right front pants pocket for an extended period of time. Observations were made at least daily for keychain failure. The experiment was repeated four times.

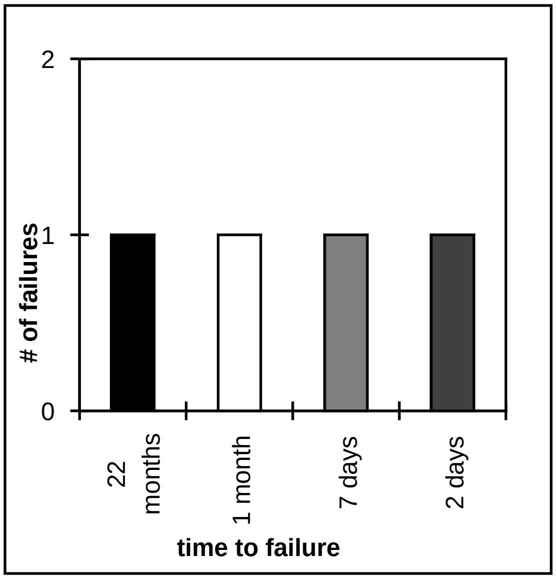
The author hypothesized three modes of keychain failure: die detachment, spontaneous mass-energy conversion, and anisotropic pseudomutogenesis. Die detachment was further divided into catastrophic (where the die fractures after detachment) and non-catastrophic (where the die is recovered intact) sub-modes. Figure 2 clearly shows that catastrophic die detachment is the dominant failure mode.

Figure 3: Failure Mode Statistics



The time to failure of the observed components varied widely and is charted on figure 3. Three of the four components tested had very short times to failure. This suggests gross manufacturing and test problems.

Figure 4: Time to Failure



Conclusions

We have seen that Pentium® processor keychains could be the fastest-growing and lucrative segment of Intel's market. Unfortunately, such products fail in the field with a very low MTTF from catastrophic die detachment. The problem is exacerbated as Intel expands its silicon jewelry line to Flash memory earrings, Pentium Pro® processor belt buckles, and maybe even i960 clitoral studs.

The author recommends a much more rigorous product burn-in before keychains are sold to the end user. Each employee could be required to carry around keychains in every pocket for two week burn-in periods to weed out the parts destined for early mortality. Given 40,000 employees and an average of three pockets per employee, Intel could still burn-in up to 60,000 keychains per week. College interns could be hired to greatly expand test capacity during summer months. The enhanced burn-in should be used before Intel begins shipping the new line of Pentium® processor keychains with MMX technology.

The biggest drawback of this study is an insufficient statistical sample. If any generous patron of the sciences would grant the author sufficient funds to purchase 10,000 keychains, a much more rigorous and complete study could be performed.