Appreciating Digital Materials for Longevous Computational Artifacts

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ABSTRACT

While we benefit greatly from rapid advances in the technologies and design of consumer electronics, the flip side of the coin is that the associated digital artifacts obsolesce quickly, with significant cultural and environmental impact. In design literature, attempts to explain and counter this phenomenon often foreground social and personal motives. We would like to contribute comments on a pertinent technical topic, focusing on the issue of durability in modern microelectronics. Responsible innovation requires that designers be mindful of long-term use and design accordingly, using appropriate materials. We argue that, for interaction designers, this relates to a sophisticated understanding of the properties of microelectronics, and introduce relevant knowledge.

KEYWORDS

Longevity, durability, sustainability, microelectronics, materiality, wearout, electromigration.

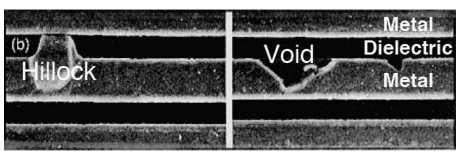

Figure 1: Microscope image of electromigration-induced "hillock" and "void" deformations on conductive interconnects in microelectronic circuit. Hillocks tend to cause short circuits between sites that should not connect, while voids lead to open circuits by prohibiting current flow. Even though devices can be engineered to counter them for some time, defects like these eventually accumulate and cause total failure. (Image from [12].)

INTRODUCTION AND BACKGROUND

The technologies that underlie interactive consumer electronics progress at a fast pace, and businesses continuously capitalize on these developments through rapid, recurrent product development cycles. This process, where more and more advanced devices are brought to market periodically, continuously creates value for both consumers and businesses in a reasonably efficient manner. Its downside is significant, multi-pronged impact on culture and the environment, as old generations of

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devices are discarded due to obsolescence. The vast majority of contemporary computing artifacts are intentionally[1] designed, manufactured, and marketed based on the premise that they will be discarded within a few years [6]. Many scholars foreground business factors, along with social and personal motives, in explaining this phenomenon [5, 6, 19, 20]. The argument is that businesses desire recurrent profits, and consumers desire the latest widgets. This is a valid analysis, but we propose that a more fine-grained examination of the underlying technical factors can have the potential to inform design-driven shifts of the status quo for the better. The fundamental desires of consumers and corporations, after all, are not easy for product and interaction designers to influence; but technical suboptimalities may be conquered through design innovations on products and processes. To this end, this paper calls attention to the issue of durability in modern microelectronics. An appreciation for the characteristics of digital materials in long-term use and appropriate design can contribute to the responsible innovation agenda in interaction design. Concretely, this relates to a sophisticated understanding of some properties of microelectronics, which we introduce in this paper.

Our position follows from how the notion of "materiality" is handled in interaction design literature (see sidebar). Both users and designers have certain mental models for how they expect certain materials, and therefore the artifacts made out of them, will behave. For example, one well-known approach to modulating users' mental models of materials with regard to longevity is based on the use of natural, durable, and repairable materials for structural, decorative, and interactive purposes to invoke perceptions of durability and familiarity [18, 23]. Further, as noted in a study on a Jacquard loom from the mid-1800s [9], it is often possible to reveal information about computational abstractions that drive functionality through "materiality" and "graspability." Another observation in the same study is that material qualities of the loom motivate a sentimental bond between it and the craftspeople involved in its operation. Such designs can be contrasted with today's commodity computers (especially mobile devices), which are built around monolithic, irreparable circuit boards that cannot be accessed by most end-users; with highly generic, mutable user interfaces.

[1] While in some cases, rapid obsolescence is desired by the manufacturer to optimize for profit, in other cases a reduced life expectancy must be accepted as the price of optimizing for other design parameters such as cost, weight, speed, etc.

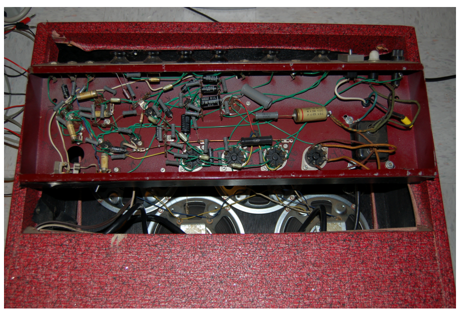

Figure 2: "Point-to-point" wiring on a guitar amplifier from the 1960s, allows for repairs. (Image by Ian Abbott, CC BY-SA 2.0)

THE LIMITATIONS OF MICROELECTRONICS AS A DESIGN MATERIAL

Modern computer hardware cannot be taken for granted as longevous design material. Microelectronic components in modern consumer devices are simply not designed to last for decades, even when there are no defects or usage issues. Electronic components under regular use continuously damage themselves over time and inevitably degrade their own functionality [22]. The processes that result in such damage have to do with the innate physical properties of these devices. Electromigration, which denotes the displacement of conducting material in circuits by continuous current flows (see Figure 1), is one such destructive mechanism that ensues under regular use [14]. Other mechanisms of failure have to do with heat- and radiation-driven distortions in the microstructures of the semiconductor and insulator layers [21]. Mechanisms like these, as well as other macroscopic of failure modes (e.g.

The theoretical notion of interaction designers giving "form" to "digital materials" is a common theme in the literature [24]. It has been discussed based on various foundations, at different granularities, and engaging with many social and practice-related issues [8, 11, 13, 16, 17, 25]. Code and electronics are often the foci of these discussions, though scholars have considered, for example, human movement [1, 3, 15, 27], drones [4, 10], and light-based machine-to-machine communication [26] as materials for interaction design.

simple mechanical breakdown due to impact etc.), tend to affect tightly packaged microelectronics more than circuits with larger components (see Figure 2), since microelectronics have delicate features and are more difficult to cool down.

Furthermore, while most mechanical artifacts can be somehow maintained or repaired, microelectronics are often designed to be thrown away when they fail. For much of modern consumer electronics, repairs may cost orders of magnitude more than the cost of replacing the whole device. Of course, there are devices are designed to enable replacing certain circuit boards or individual components, but this makes sense only within a limited timeframe, since the components must be available from vendor that manufactures and distributes them. In turn, manufacturing particular integrated circuits requires an investment that only makes sense if there is demand for large quantities of them [7]. Thus, in the long run, as technologies and market forces change, particular microelectronic components phase out of availability.

Limitations such as these are innate to the technologies that enable modern computing artifacts to have their current forms and functions. If repairability and longevity were primary concerns, it would likely not be possible to pack the affordances of modern computing into mobile form factors.

CONCLUSION

We wish to motivate designers working with "digital materials" and computational artifacts to develop a sophisticated understanding of the "material properties" of electronics, particularly in relation to longevity and repairability. We believe that this will inform design decisions related to long-term use, and have the potential to inform designs with positive sustainability impacts. In previous speculative work, we proposed design concepts founded on these motivations [2]. In future work, we aim to investigate what resources and tools might empower designers to capitalize on these ideas, and undertake constructive design research around artifacts that target consumers. We hope that the workshop will inform us to better align this future work with the responsible innovation agenda.

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