Beyond Prototyping Boards Workshop Position Paper: How Open Silicon Could Transform the Prototyping Board Landscape

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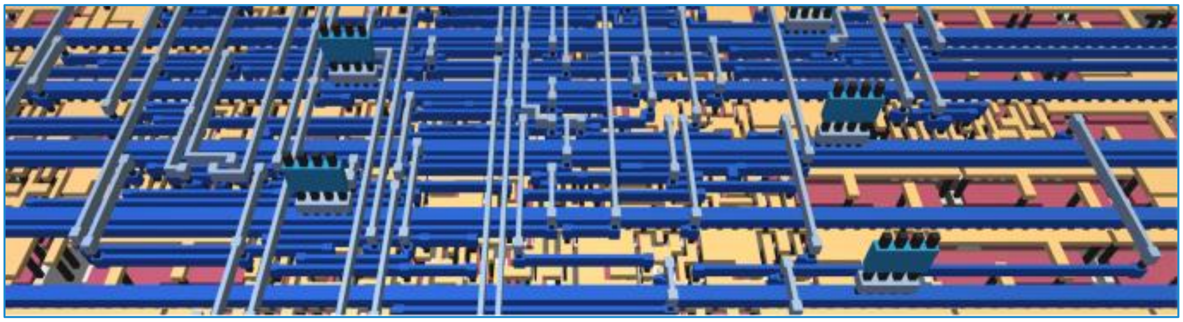

Fig. 1: Automated rendering of GDSII from the author's design [1] within the Tiny Tapeout Project

Open and accessible design and fabrication of silicon appear to be a solution to the structural weaknesses of the microelectronics industry. For HCI researchers, makers, and educators, this provides new opportunities to develop flexible and extendable prototyping solutions that span all levels of abstraction from transistor to prototype, to low-volume production run product. By opening up designs and tools, we can break down information barriers between the layers of abstraction. The accessibility of this novel approach will mean software and hardware tools can be supercharged to help researchers and makers realize their ideas more easily.

1 INTRODUCTION

Most microcontroller-based development and prototyping boards rely on vendor-specific devices that have been designed for commercial products and have closed silicon design. Support for using these microcontrollers is limited, and in many cases, when provided with a datasheet or programming guide, it is up to the user to have the domain-specific knowledge to translate this into a hardware abstraction layer for their project. The Arduino project [2] and other open-source software tools [3], [4] have done an excellent job of hiding this abstraction from the user. The open-source approach has meant this work doesn't need to be duplicated, however, this all relies on organizations and individuals with the domain-specific knowledge to implement hardware abstraction layers for these tools. This is a huge continuous effort, and will not be able to cover all the features of all the development boards that one might want to use. Since the designs of the parts are proprietary, the vendors must provide information to enable abstraction for the individual use cases in diverse ways.

The microelectronics industry has developed barriers to entry which are economic, cultural and technical: focusing investment on speed and complexity has supported significant growth, but has not enabled diverse, widespread design and fabrication innovations across the community. The sector must manage ever more complex processes, overcome quantum limits of miniaturization, and rethink entrenched architectures according to energy rather than speed. However, a scarcity of talent and holistic design capabilities is partly a function of the narrow opportunities to engage with and innovate in a sector with limited flexibility and underpinned by challenging environmental and financial costs. Democratizing the design and fabrication of semiconductor devices could create a new wave of open-source silicon projects, providing more diverse technical innovations and solutions, while improving the value of existing inaccessible facilities and approaches.

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While there does exist a wide range of different prototyping boards [5] , in this position paper, we will explore primarily with a focus on integrated microcontroller style prototyping boards, how open-source silicon design and manufacturing tools could help shape the next generation of interactive device prototypes and small-scale production runs by enabling citizen developers and manufacturers. We will then go into detail, looking at a couple of examples from our own experience with custom and open-source silicon projects.

2 OPEN SILICON

Here we define open silicon as anything that can democratize the production of circuit systems from architectural design to packaged circuits. Various approaches exist , including but not limited to the examples we go into here.

2.1 Hardware Descriptions

Members of the open-source community are already publishing their implementations of different designs online on websites such as OpenCores [6] and GitHub. Notably, various implementations of the open-source instruction set architecture RISC-V have emerged [7], [8]. The availability of open designs has enabled more hobbyists and prototypers to start programming Field Programmable Gate Arrays for their projects. This has been amplified by the recent developments in reverse engineering the bitstreams to program them, notably in the lattice semiconductor range of FPGAs [9].

2.2 PDKs

Process Development Kits (PDKs) are the instructions that describe how to convert a design into something manufacturable by a fabrication company on a specific technology node. Fabs have traditionally kept their PDKs private, requiring semiconductor designers to sign strict NDAs to avoid leaking information about their particular technology to other parties. Recently, however, Google has sponsored a number of projects to support GlobalFoundaries and Skywater Technology to open up some of their more mature technology nodes [10] and has sponsored individual designs to be made part of Multi-Project Wafers (MPWs)[11].

2.3 EDA Software

Electronic Design Automation (EDA) tools are a suite of tools that help designers go from specifications to fabrication of design files. The conventional approach is for designers to license these from large companies. Open-source alternatives are being developed including Open Lane [12]. The success of Open source tools in PCB design like KiCAD [13] presents a huge amount of optimism towards these efforts.

2.4 Fabrication Tools

Finally, there is the fabrication of the devices themselves. This is still a somewhat untouched area of the field and requires burrowing down to the bottom of the abstraction model. There are various examples of projects that have looked into opening up the space such as the Libre Silicon Project [14] , however, it still uses traditional semiconductor manufacturing technologies. There is clearly a huge scope to take a step back from the existing methodologies and come up with novel fabrication approaches to create new prototyping boards and interactive tools around open silicon. In this space there is an enormous potential for future research. In particular, working out how to provide a safe, low-risk set ups for citizen manufacturers, much like the what the RepRap [15] project did for additive manufacturing in the prototyping space when the existing 3D printer patents expired.

3 RAISING THE INFORMATION BLOCKADE PROJECT [

Microcontroller device manufacturers avoid sharing proprietary information such as licensed IP cores, or process information due to market economy pressures and the strict NDAs from the foundries that produce their devices. This means that in order to share the technical details of the chips they produce, they translate the design information into human-readable datasheets and perhaps programming guides. To then make use of the device, one must mechanically convert this datasheet into some kind of abstraction layer for a particular board. This extra level of abstraction creates an additional step in the information flow between the design and use of the part. The translation is a significant amount of non-creative domain-specific human effort and could easily be overcome if designs were made open. Projects already exist to mitigate tedious effort in the space of board design using existing circuits [16], however, this still relies on some computer representation of the devices the circuits use themselves. In a world where designs were open, the original hardware descriptions would be used as the input to these tools.

Open designs would mean that they could be inspected by someone who was looking to add features to existing designs. Large circuit designs already are very modular. It's conceivable that someone wishing to add different peripherals or change amounts of memory on a chip, re-synthesize and have it manufactured. Researchers and makers would no longer be constrained by the hardware that was available. If a project required more memory, pins, or a different kind of physical interface, either a more integrated tool flow that had better introspection of available devices in the space could suggest an existing device or the tools could automatically create a design that fit the architectural requirements of the project.

The increased openness and a larger library of existing designs will naturally increase interest and education within the field. Just as we saw with open-hardware [17], we expect this new interest to create a positive feedback loop of education and improved tools and resources around semiconductor design and manufacturing.

4 EXAMPLES OF OPEN AND CUSTOMIZED SILICON IN PROTOTYPING TODAY

Even though open silicon is still maturing, its rise has already had an impact on our work in prototyping and human-centered design. It provides hope that we are heading in a new direction with prototyping boards and education around the space.

4.1 RP2040 - Custom silicon for makers and educators

Notably, the Raspberry Pi foundation released the Raspberry Pi Pico in 2020 [18] based around the RP2040 chip, a custom microcontroller designed specifically with non-specialists in mind. This new development helped promote the idea that prototyping boards don't need to be developed around microcontrollers for commercial applications, and can exist in their own right. The Pico has a number of features specifically geared towards rapid prototyping, and the foundation has put a great deal of effort towards documenting the board and making it more accessible Though not based on open silicon because it still relies on closed aspects of the manufacturing cycle, the RP2040 chip does give a glimpse into what might be possible in the realms of customization for specific use cases, especially in the field of HCI.

A current project requires a low-cost controller for Phased Arrays of Transducers (PATs) for ultrasonic interaction devices. To generate custom acoustic fields, the phase and amplitude or each transducer needs to be controlled. This is done by sending a rapid serial stream to a chain of shift registers that drive each of the transducers. Existing open designs for phased arrays [19], use prohibitively expensive FPGAs which rely on proprietary tool flows. The RP2040's Programmable IO (PIO) pins, which were intended for makers to create additional hardware interfaces and liberate main processor cores for other tasks, allowed us to quickly come up with a new approach to optimize timing control the amplitude and phases of a comparable number of transducers to the FPGA.

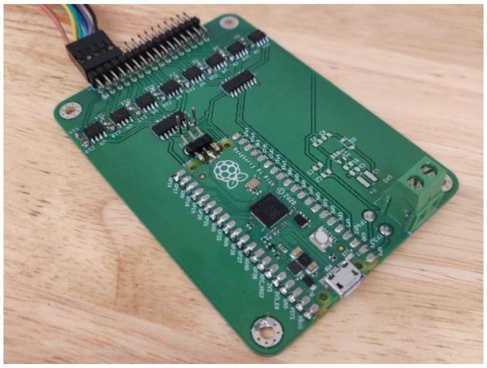

Figure 2: A prototyped ultrasonic transducer driver circuit using RP2040

4.2 Tiny Tapeout - Open PDKs and open education

The "Tiny Tapeout" project[20] addresses the whole flow of semiconductor development from design to manufacturing. Within a couple of hours an audience can be taken from the basics of semiconductor design through to dragging and dropping logic gates in a web-based EDA program, to having a GDSII, the standard file type for describing hardware to be given to a semiconductor foundry. There is an option to submit designs to make up a part of one of the MPWs provided by Google's open silicon initiative. Workshops are hosted in educational settings as well as in hackspaces and makerspaces. Opportunities like this present an optimistic outlook for the future of open semiconductors. Open and accessible designs may only still be simple, but at this rate of progression, it is foreseeable that we might start to see citizen manufacturers designing their own customized prototyping boards for any number of applications.

5 CONCLUSION

A shift in our approach to semiconductor design and manufacturing tools may be just what we need in order to kick-start a revolution in the design of new custom prototyping platforms for human-centered design. Openness will foster education that will make the field more accessible, in turn improving the automation tools to work across all levels of abstraction. New automated tools can improve customization, which along with novel fabrication technologies may just make ubiquitous computing a reality through citizen design and manufacturing.

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ABOUT THE AUTHOR

Oliver Child is a first year PhD student and primarily identifies as a maker. He’s excited by all new kinds of manufacturing and prototyping, and enjoys building projects around them. Having spent some time working at a semiconductor company before starting his PhD, he is motivated to fix the issues engrained in the industry through his research. Currently he is exploring the application of acoustic forces to create localized cleanrooms, to enable citizen manufacturers to make their own semiconducting devices outside of traditional foundries.

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