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Project Topic: What is next after Silicon-based circuits?

During class a while back, we viewed a video about the production of silicon, and the importance of its applications in digital logic circuitry. Throughout watching it, I couldn't help but think, "There has to be something else that will be more efficient than this eventually, right?" Something that doesn't require as much tidy maintenance, and maybe not as fragile and prone to failing once actually created into chips, as we saw with the red dots on the silicon wafer that was brought to class. I decided to do some research and make this the topic of this project, as it is imperative that as time goes on, our specialized hardware will become smaller and faster, as proven by Moore's law. But before we dive into the potential and possibilities of replacement semiconductor materials, we must first understand the importance of silicon, and why it is so commonly found in modern technology today.

Silicon is the second most abundant material in the earth's crust, making up approximately 27.7% of it, following only oxygen and is the seventh most copious material in cosmic space. While many of its compounds do not apply to electronics, it should be known that it is a widely versatile material that has several applications in other common resources such as silicon dioxide (silica) for glass, or silicon hydride (silanes) for adhesives. However, some do and are thought to be replacements for base silicon, such as silicon carbide, which we will discuss later.

Aside from it being extremely available to us, there are plenty of other uses that silicon provides to electronic circuits. The first and most prominent is that it is a phenomenal semiconductor. A semiconductor is essentially the cross between a conductor and an insulator, as it has behaviors of both. It is made to control the amount of conduction, not insulation, hence why they are not called semi-insulators. In electronics, it's a matter of keeping the glass half full not half empty, as in semiconductors, valence and conduction bands are both partially filled, having a smaller energy gap between the two than what of insulators. It is also important to note that the reason conductors are not used other than semiconductors, is that conductors have a low resistivity to controlling flow, while semiconductors have a moderate resistivity and also a moderate conductivity, making it perfect for electronics, as electrons are not free to flow throughout the element the semiconductor uses. But what makes silicon a better base material for a semiconductor than others, such as germanium? It is because these electrons are not as prominent. We want to have just enough flow so that the temperature regulation in semiconductor crystals is controlled and the charge leakage is minimal. And like we said before, semiconductors like germanium and gallium are extremely rare, and difficult to find a large quantity of silicon. So, with this all being said, what is the point in bringing up the idea of replacing silicon? There are possibilities we must consider that have recently been discovered.

In Moore's law, it is said that as time passes, the number of transistors in a single chip will double every two years, exponentially increasing the speed and energy efficiency of the microprocessor. This is quite a popular topic in computer science, whether it is dead already, will die soon, or never die. But I feel the more important way we should apply Moore's law in today's technology, is not the number of transistors in a chip, but a chip's density and how they are applied. If we are to say that the number of transistors should double each year, at the time Moore's law was created, then that should also be said for the processing power. Take a look at the table provided below showing a small comparison to demonstrate this. In two different chips, we see two very recently created chips from two different companies AMD and Apple, consisting of transistors that double every two years or less. However, there is one thing we should notice immediately upon observation. Although both do follow Moore Law's initial intent,

Company	Chip	Transistors	Release Date	Transistor Density (transistor per squared millimeter)
AMD	Ryzen 7 3700X	5.99 Billion	July 7th, 2019	30.1 Million

	Ryzen 7 5800H	10.7 Billion	January 12th, 2021	59.44 Million
Apple	M1	16 Billion	November 17th, 2020	134.5 Million
	M1 Pro	33.7 Billion	October 18th, 2021	137.6 Million

Sources provided below in listed citations

Notice how the transistor density for AMD doubles, yet Apple stays relatively the same, despite both doubling in transistor count. One can say that at its most strict aspect, this disproves Moore’s law as density decreases, as even just one chip would falsify its intentions. Increasing density with more transistors means keeping the chip's size as small as possible. Apple can put more transistors on its device, however, pursues the same proportion between M1 and Pro densities. Regardless of a company's decisions, we should consider ways that can help this density keep increasing, as with Moore’s law, we want faster AND smaller chips to be pursued. This brings us to the very topic we are discussing. Will replacing silicon help the longevity of proving Moore’s law validity? We are seeing a soft cap of transistor density, processing power, and clock rates, not only on Apple’s chips. So how can a different material help with this, and in what ways we have discussed make silicon better or worse?

Although there are several to discuss, there are two key materials that have been in popular contention for discussion within the past few years. The first is Cubic Boron Arsenide (we will call CBA for shorthand). Silicon, although it has great electron movement throughout its structure, is less accommodating to its positive counterpart mobility, being electron holes. It is important for a semiconductor to be great for both aspects. Alongside this, we must consider how silicon handles heat. Each and every transistor generates a small amount of heat, which is why cooling is such a common and important practice when building a computer or console. If not dissipated well, transistors may die and potentially damage the entire system. It turns out that CBA beats silicon’s performance in both of these, according to Jungwoo Shin of MIT, stating that it has “10 times higher thermal conductivity than silicon.” Another team of researchers from several different backgrounds and foundations also states from two different sources, “we experimentally measured thermal conductivity of 1200 watts per meter per kelvin and ambipolar mobility of 1600 centimeters squared per volt per second,” and, “The thermal conductivity of BAs, 1000 ± 90 watts per meter per kelvin meter-kelvin, is higher than that of silicon carbide by a factor of 3 and is surpassed only by diamond and the basal-plane value of graphite.” However, despite all of these improvements, we are very far from implementation, as we are only discussing the potential. CBA is still very scarce in comparison, and it is said that we have many years before we can even come close to mass producing it into modern computer chips, considering commercialized uses and the equal amount of productivity.

The other, which is a direct improvement, is silicon carbide. Unlike CBA, there actually is already modern implementation for this semiconductor, and that is mainly prominent in Tesla and other electric car manufacturers. Silicon Carbide provides the same benefits to computerized chips as CBA, however, it goes without saying that it is extremely more accessible and can be a perfect stepping stone to the next best semiconductor on the commercialized market. Additionally, silicon carbide only needs a tenth of the amount of silicon that a silicon base chip needs to provide the same amount of voltage, making it highly efficient without expending nearly as much resource. The main reason why it has taken so long to come across these benefits is that silicon and carbon are not often found together on the earth, and present quite a risk when other technology might not be caught up to its potential, as it is an investment for companies to dedicate a certain increase in manufacturing cost to reap the benefits when the technology is still relatively new.

There are other honorable mentions that have made breakthroughs in the world of semiconductors, being hydrogenized diamonds, various phosphorus compounds, hafnium diselenide, and zirconium diselenide, some of which have far better properties and uses than that of previously mentioned materials. However, as silicon carbide could take years to implement into mass production of computer chips, these could take decades or not at all.

When it comes to the actual production of silicon, like stated previously, it is extremely fragile and prone to breaking. Many times, cracks can only be seen at a microscopic level, as each singular wafer is only 160 micrometers thick, and still has potential to be even thinner. Reducing the size of each wafer means less loss of production cost when this breaking does happen. However, silicon carbide breaks a lot less frequently, as when carbon is added to silicon ,we get one of the hardest materials in the world, only short of compounds of boron and diamond, which we have also mentioned.

In summary, with each generation of computer scientists and engineers, the basis of our research is simple. We of course, care about other aspects, yet we always come back to the same set of questions, “How can we make something faster?...”What we can implement to make this less costly and more efficient?” Silicon Carbide seems to be that next step upon intermediate review. It beats base silicon in every fashion, and is the only improvement upon it that isnt costly to produce.

I truly believe that what we have discussed is an important topic that should always be at the forefront of future findings. Similar to what a parent wishes to pass on to their children, we must be able to distinguish the good/bad and carry on what has been found to be worth keeping. Ultimately, we will come to a very bright future, including the world of electronic commerce.

Sources next page…

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