Understanding the EV Semiconductor Chip Sustainable Supply Chain Chip Shortage

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Received: Dec 29, 2023, Revised: Jan 10, 2024, Accepted: Jan 13, 2023, Published Online: Jan 16, 2024

Reviewers: Anonymous Peer Review


Abstract

Semiconductor chips play a pivotal role in modern technology, with their significance heightened by the growing electric vehicle (EV) industry. As vital components powering electric powertrains, advanced driver-assistance systems (ADAS), and in-car infotainment, semiconductor chips have become the linchpin of the automotive industry's transformation. The escalating global demand for EVs has, however, triggered a semiconductor chip shortage, leading to systemic disruptions in the supply chain.

This study adopts a comprehensive approach to understanding the repercussions of the chip shortage within the automotive sector. Our method involves examining news articles about the semiconductor shortage, which worsened due to the COVID-19 pandemic. From this examination, a framework is created that explains the reasons for the shortage and its consequences. Through these analytical frameworks, the paper draws essential lessons and implications regarding the initiation, propagation, and enduring nature of systemic disruptions. The findings provide valuable insights into the complexities of supply chain dynamics, offering an in-depth understanding of how disruptions manifest and persist over time. As semiconductor shortages continue to affect various industries, including the automotive sector, these insights contribute to the ongoing discourse on the sustainable management of semiconductor chip supply chains. This paper aims to delve into the intricacies of the EV semiconductor chip sustainable supply chain, shedding light on the factors contributing to the chip shortage and exploring potential solutions for a resilient and sustainable future.

Keywords: Semiconductors, silicon carbide, electric vehicles, chips shortage, automotive industry.

1. Introduction

Semiconductor chips serve as the backbone of modern technology, gaining increased significance alongside the proliferation of Electric Vehicles (EVs). These chips play a pivotal role in powering essential components like electric powertrains, advanced driver-assistance systems (ADAS), and in-car
infotainment, thereby becoming indispensable to the evolutionary trajectory of the automotive industry. However, the surge in global demand for EVs poses an unprecedented challenge to the semiconductor industry, necessitating rapid adaptation to this transformative phase. The growing demand for semiconductor engineers in the United States has reached a critical juncture, with an estimated need for over 50,000 new professionals in this field over the next five years[1]. This demand stems from the ambitious plans to establish new semiconductor factories, research laboratories, and companies within the country. Recognizing the strategic importance of semiconductor technology and its impact on various industries, the U.S. administration has proactively taken steps to address this workforce shortage. The enactment of the Chips and Science Act reflects a concerted effort to drive actions and initiatives that will not only meet the immediate demand for skilled semiconductor engineers but also foster innovation, research, and development in the semiconductor industry to ensure long-term growth and competitiveness[2]. The semiconductor industry is racing to develop new chips and technologies to meet the demands of the automotive industry. Companies are also investing in research and development to find more efficient and sustainable methods of producing chips. This will lead to significant advances in the automotive industry.

1.1 Context of Semiconductor Importance in EV Evolution

The primary semiconductors found in the modern-day electric vehicle are the Silicon Carbide-based Metal Oxide Semiconductor Field-Effect Transistors (SiC MOSFETs). The timeline for the development of SiC MOSFETs, as shown in Figure 1, reveals significant milestones since its discovery in 1824[3]. In 2001, the first commercial SiC device was introduced by Infineon, marking the beginning of SiC MOSFETs' entry into the market. Over the years, other major players like STMicroelectronics and CREE have made crucial advancements, with mass production and the introduction of SiC MOSFET-based inverters in vehicles such as Tesla's Model 3 in 2017[4]–[6].

SiC MOSFETs have reshaped the qualitative utilization of semiconductors in vehicles. They serve vital functions in power electronics for powertrain electrification and as high-performance computing units, data transmitters, and sensors in the reconfiguration of software and electronics architectures. Electric vehicles rely heavily on semiconductors, which are crucial for controlling the powertrain, regulating the battery, and managing the entire vehicular system. The complexity of EVs amplifies the importance of semiconductors, and as the industry transitions towards EVs, their role is set to become even more significant. The use of SiC MOSFETs, known for 75% lower switching losses and 50% lower conduction losses than their silicon counterparts, has led to a potentially 300% increase in power density, facilitating advances in automotive technology [7].
The ongoing electrification and software integration in vehicles are steering a major transformation in the automotive landscape. This shift not only escalates the quantitative demand for semiconductors but also reshapes their qualitative utilization within vehicles. Semiconductors are now evolving into strategic components, serving vital functions in power electronics for powertrain electrification and functioning as high-performance computing units, data transmitters, and sensors in the reconfiguration of software and electronics architectures. The emergence of "software-defined vehicles" [9] mandates a departure from the traditional perception of semiconductors as mere intermediate products. Instead, they have emerged as key components critical to shaping the future of the automotive sector. Electric vehicles (EVs) are particularly reliant on semiconductors, as they require specialized components to control the powertrain, regulate the battery, and manage the entire vehicular system[10]. The complexity of EVs means that semiconductors are even more important than traditional vehicles. As the automotive industry moves towards EVs, semiconductors will assume an even more important role in the future. Semiconductors will become a critical component of the automotive sector[11], [12].

1.2 The Semiconductor Chip Shortage Challenge in the EV Industry

A significant obstacle facing the EV industry is the persistent shortage of semiconductor chips, a challenge with far-reaching implications for both manufacturers and consumers. This scarcity is a direct consequence of the surge in EV demand and marks a turning point for semiconductor use in the automotive sector. The ensuing chip crisis has compelled automotive companies to reconsider their semiconductor strategies and collaboration approaches with semiconductor industry counterparts[13]. This paper explores the multifaceted aspects of the semiconductor chip shortage, addressing the industry's need for strategic redefinition and cooperative strategies to navigate this critical juncture. Furthermore, it explores the potential opportunities arising from the crisis, presenting avenues for the redesign of semiconductor use and improvements in overall sustainability within a circular economy framework [14], [15]. This study also identifies potential risks
stemming from the semiconductor chip shortage, including challenges such as price inflation, disruptions in the supply chain, and potential employment ramifications. Finally, the paper provides strategic recommendations for stakeholders to effectively navigate this intricate and challenging landscape.

2. Contextual Background and Review of Relevant Literature

The recent chip crisis has underscored these developments and highlighted the associated challenges faced by automotive companies. This crisis demands a comprehensive reevaluation of semiconductor strategies and collaborative practices within the semiconductor industry. It serves as a critical moment in the trajectory of semiconductor utilization within the automotive sector. Simultaneously, the crisis presents an opportunity for companies and policymakers to not only redefine semiconductor applications but also enhance the overall sustainability of material flows toward a circular economy.

During the emergence of the semiconductor industry in the 1950s, the automotive industry stood as an established sector, playing a leading role in post-war economic development. However, up until the 1950s, the automotive industry primarily relied on mechanical, metalworking, and thermodynamic technologies, with minimal incorporation of electronics[16]. The introduction of semiconductor technology in the 1960s marked a transformative phase, leading to the development of application-specific circuits for functions such as ignition, fuel injection, and alternator control. This transition laid the foundation for the gradual replacement of mechanical and electromechanical control modules with electronic control units (ECUs) by the mid-1970s.

The commercialization of the microprocessor by Intel in the 1970s further accelerated the integration of semiconductors into vehicles, enabling the development of programmable vehicle controllers[17]. This shift facilitated the transition from individual ECUs for specific functions to more versatile ECUs capable of performing multiple functions, connected through various bus systems. As the complexity of semiconductor control increased, the number of semiconductors employed in vehicles surged, addressing diverse functions such as electrical voltage regulation and flow control. The contemporary vehicles of established manufacturers feature an intricate Electrical/Electronic (E/E) architecture, comprising numerous interconnected ECUs.

In recent years, the electronics industry has been grappling with a shortage of semiconductor chips, with the automotive sector particularly hard-hit. Car manufacturers worldwide faced the brunt of this crisis, experiencing production[18], delayed shipments, and, in some cases, factory shutdowns. The shortage triggered supply chain disruptions, resulting in delayed shipments. Additionally, to mitigate the effects of the shortage, some plants opted to shut down temporarily, redirecting their focus towards more profitable truck assembly. This strategic move was made to address margin concerns amidst the semiconductor chip scarcity. Furthermore, the semiconductor shortage caused a notable extension in manufacturing lead times. What was once an average lead time of three to four months surged to an average of 10 to 12[19]. This increase in lead times added another layer of complexity for manufacturers, compounding the challenges.
posed by the scarcity of semiconductor chips in the automotive industry. The repercussions of this shortfall were profound, manifested by a worldwide financial setback amounting to $210 billion in 2021 and resulting in the discontinuation of production for more than 8 million vehicles.[20]

![Figure 2: Semiconductor chips inside a modern vehicle](image)

Table 1.0: "Overview of Semiconductor Components in Modern Vehicles: Categories, Functions, and Approximate Quantities"

<table>
<thead>
<tr>
<th>Category</th>
<th>Semiconductor Component</th>
<th>Function/Purpose</th>
<th>Approx. No. in Modern Vehicle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microcontrollers</td>
<td>Engine Control Unit (ECU)</td>
<td>Manages engine performance and efficiency</td>
<td>1-3</td>
</tr>
<tr>
<td>Microcontrollers</td>
<td>Transmission Control Unit (TCU)</td>
<td>Controls automatic or semi-automatic transmissions</td>
<td>1-2</td>
</tr>
<tr>
<td>Microcontrollers</td>
<td>Body Control Module (BCM)</td>
<td>Manages various body-related functions</td>
<td>2-5</td>
</tr>
<tr>
<td>Microcontrollers</td>
<td>Airbag Control Module</td>
<td>Controls deployment of airbags in case of an accident</td>
<td>1-2</td>
</tr>
<tr>
<td>Microcontrollers</td>
<td>Advanced Driver Assistance Systems (ADAS) Controllers</td>
<td>Manages safety features such as collision avoidance lane-keeping, etc.</td>
<td>2-5</td>
</tr>
<tr>
<td>Power Management</td>
<td>Voltage Regulators</td>
<td>Regulate voltage levels for various components</td>
<td>50-100</td>
</tr>
<tr>
<td>Power Management</td>
<td>Power MOSFETs</td>
<td>Power switches for efficient energy management</td>
<td>70-200</td>
</tr>
<tr>
<td>Power Management</td>
<td>Power ICs</td>
<td>Integrated circuits for efficient power distribution</td>
<td>50-100</td>
</tr>
<tr>
<td>Memory</td>
<td>Flash Memory</td>
<td>Stores software/firmware and data</td>
<td>1-3</td>
</tr>
<tr>
<td>Memory</td>
<td>DRAM</td>
<td>Provides volatile memory for various applications</td>
<td>1-3</td>
</tr>
<tr>
<td>Connectivity</td>
<td>Controller Area Network (CAN)</td>
<td>Enables communication between various car systems</td>
<td>2-4</td>
</tr>
<tr>
<td>Connectivity</td>
<td>Ethernet</td>
<td>High-speed communication for in-car networks</td>
<td>1-2</td>
</tr>
<tr>
<td>Connectivity</td>
<td>Bluetooth and Wi-Fi Modules</td>
<td>Enable wireless connectivity for infotainment, etc.</td>
<td>2-4</td>
</tr>
<tr>
<td>Display/Graphics</td>
<td>Graphics Processing Unit (GPU)</td>
<td>Drives infotainment and navigation displays</td>
<td>1-2</td>
</tr>
<tr>
<td>Display/Graphics</td>
<td>LCD and OLED Displays</td>
<td>Display information to the driver and passengers</td>
<td>2-5</td>
</tr>
<tr>
<td>Sensors</td>
<td>Accelerometer</td>
<td>Measures acceleration for stability control</td>
<td>1-2</td>
</tr>
<tr>
<td>Sensors</td>
<td>Gyroscope</td>
<td>Measures orientation for stability control</td>
<td>1-2</td>
</tr>
<tr>
<td>Sensors</td>
<td>ABS Wheel Speed Sensor</td>
<td>Monitors wheel speed for anti-lock braking system</td>
<td>4-8</td>
</tr>
</tbody>
</table>
3. Understanding Silicon Carbide (SiC) Semiconductors

Silicon carbide (SiC) is a semiconductor material that stands out in the electronics industry due to its unique properties. Unlike traditional silicon semiconductors, SiC is known for its wide bandgap. This term, ‘wide bandgap’, refers to the energy required to move electrons from the material’s valence band (where they are bound to atoms) to the conduction band (where they can move freely and conduct electricity). SiC’s wide bandgap allows it to sustain higher voltages and operate at temperatures that would disable most silicon semiconductors. The robustness of SiC is further exemplified by its ability to withstand high electric fields without breaking down, making it an excellent candidate for high-power and high-frequency applications. Additionally, SiC semiconductors are more efficient than their silicon counterparts because they have lower resistance and can switch on and off faster, which reduces energy losses during power conversion processes. This is why SiC Metal-Oxide-Semiconductor Field-Effect Transistors (MOSFETs) are gaining traction in the EV industry; they allow for more efficient control of electricity within a vehicle’s power systems.

In the context of electric vehicles (EVs), the power control systems are critical to performance. SiC MOSFETs, which are transistors made from SiC semiconductor material, are becoming increasingly popular in EV applications. They manage the flow of electricity from the battery to the motor, ensuring that power is delivered efficiently. The superior thermal conductivity of SiC MOSFETs also means they can operate at higher temperatures without overheating, which is crucial in the compact and thermally challenging environment of an EV. Their enhanced efficiency translates into tangible benefits for EVs, such as faster charging times, extended driving ranges, and improved overall vehicle performance. SiC MOSFETs can handle the high-power demands of EVs while minimizing energy losses, making them fundamental to the advancement of EV technology.

Currently, silicon-based Insulated Gate Bipolar Transistors (IGBTs) and Metal Oxide Semiconductor Field-Effect Transistors (MOSFETs) dominate the electrified vehicle semiconductor market. Due to their high dielectric strength and low on-resistance [21], silicon (Si) IGBTs are frequently used in high-power applications, including electric drive systems [22]. Silicon-based semiconductors, however, suffer from inherent limitations, such as high switching losses [23] and limited switching speeds, which ultimately limit the switching frequency of Si-IGBTs to around 20 kHz [24] [8].

Given the critical role of SiC semiconductors in the EV industry, it is paramount to safeguard their production. Disruptions in the supply of SiC can have significant repercussions, as seen during the recent global chip shortage which affected numerous industries, including automotive manufacturing. Securing the supply chain for SiC semiconductors is not only about maintaining a steady supply but also about ensuring the strategic independence and technological leadership of the sector. The scarcity of these chips during the pandemic has emphasized the need for robust and resilient manufacturing and distribution networks.
SiC semiconductors represent a significant leap forward in power electronics, particularly within the EV industry. As we transition towards more sustainable and efficient vehicles[25], the reliance on SiC technology will only increase. The need to understand, innovate, and protect this technology is crucial. Establishing a secure, sustainable, and scalable supply chain for SiC semiconductors is imperative for the future of electrified transport and the overall resilience of the automotive industry. The semiconductor landscape is evolving rapidly, and at the heart of this transformation are wide-bandgap power devices crafted from materials like silicon carbide (SiC) and gallium nitride (GaN). These materials are ushering in a new era of power semiconductors that are set to redefine the industry. In particular, SiC power chips are making a significant impact on the electric vehicle (EV) market. These chips are essential to managing the power within EVs, serving as a key element that keeps everything running smoothly. Their superior efficiency and resilience make SiC power chips a preferred choice over traditional silicon options, which is why they're becoming increasingly popular in the automotive realm. This includes applications beyond the vehicle itself, such as in charging stations, energy storage systems, and the broader smart grid infrastructure. The shift toward SiC really took off in 2017 with Tesla's adoption of these chips in their Model 3 cars. This move is anticipated to encourage a widespread transition to SiC power chips, significantly contributing to efforts to make transport and energy systems more environmentally friendly.[26]

4. The Chip Shortage

4.1 The Chip Shortage – Navigating the New Terrain of Semiconductor Supply

The semiconductor chip shortage that rattled the global automotive industry was not the result of a single event but a confluence of unforeseen disruptions and systemic vulnerabilities. A major factor in this shortage was the COVID-19 pandemic, which caused widespread manufacturing shutdowns and logistical nightmares throughout supply chains[27]. At the same time, consumer behavior shifted dramatically, increasing demand for household electronics and straining semiconductor foundries' production capacity. The combination of these factors, coupled with a complex and multilayered global supply network, created a perfect storm that left automakers and numerous other industries scrambling for critical electronic components. This shortage served as an important reminder of the vulnerability of supply chains and the urgent need for tactical changes to maintain resilience in the face of such large-scale disruptions.

4.2 Factors Contributing to the Chip Shortage

The semiconductor chip shortage, a pivotal disruption in the EV industry, can be traced to a series of compounding factors [28]:

Global Pandemic Disruptions: The COVID-19 pandemic induced significant supply chain disruptions, leading to manufacturing halts and consequent delays. The semiconductor industry, which relies on a precise balance, faced substantial production and distribution challenges.

Increased Demand for Electronics: The pandemic increased dependence on electronic devices for remote work, further taxing
semiconductor production capacities. This led to a reallocation of resources away from the automotive sector.

**Complex Supply Chain Dynamics:** The intricate nature of the semiconductor supply chain, from sourcing raw materials to delivering finished products, means disruptions can cause widespread impact, particularly affecting the ability of the automotive industry to meet EV production goals.

**4.3 Implications for the EV Industry**

The chip shortage has left a noticeable imprint on the EV industry, resulting in production delays, increased vehicle prices, and a cascading effect on the entire automotive ecosystem [27]. The post-lockdown period saw a resurgence in customer demand, compelling automobile companies to adjust to new market conditions. Geopolitical tensions have highlighted supply chain vulnerabilities, with restrictions affecting Chinese businesses and leading to hoarding behaviors [29]. The shortage has led to production disruptions, inflationary pressures, labor issues, and challenges for end consumers and dealers, significantly impacting the automotive industry [30]. The semiconductor chip shortage has had profound implications for the electric vehicle (EV) industry, leading to a myriad of challenges and disruptions:

**Production Line Closures and Feature Removals:** Initially triggered by the COVID-19 crisis, the automotive sector, including EV manufacturing, experienced a dramatic drop in vehicle demand. However, as orders surged unexpectedly, a critical shortage of automotive semiconductors forced original equipment manufacturers (OEMs) to shut down production lines and even omit popular features like heated seats from their vehicles.

**Decline in Automotive Revenues:** The inability of OEMs and Tier 1 suppliers to secure sufficient quantities of chips has led to substantial delays in vehicle production. This situation has caused a notable drop in automotive revenues, a problem exacerbated by the severe repercussions of the semiconductor shortages across the industry [20].

**Increased Costs and Supply Chain Disruptions:** External factors such as Russia's invasion of Ukraine have added further uncertainties, affecting the supply of critical materials used in semiconductor manufacturing and increasing transportation costs. This geopolitical situation has compounded the difficulties faced by OEMs in procuring essential components, thereby impacting production volumes and adding more uncertainty to the semiconductor supply chain.

**Unique Challenges in the Automotive Sector:** The automotive industry’s reliance on a "just in time" manufacturing strategy left it particularly vulnerable when demand rebounded. This approach, combined with the industry's requirement for specifically validated semiconductors and stringent safety standards, has made the impact of the shortage more severe in the automotive sector compared to other industries.

**Increased Demand for Advanced Automotive Features:** The rising popularity of vehicle electrification, advanced driver-assistance systems (ADAS), and connected-car features has led to a steady increase in the demand for automotive chips. In response, the industry has been ordering more semiconductors than needed to ensure inventory and safeguard production, contributing to a "bullwhip effect" and further complicating the supply chain.

**Long-Term Persistence of the Shortage:** The semiconductor supply chain was already under strain before the pandemic, and it is now expected that the chip shortage will continue in certain technology nodes for at least the next
three to five years. This ongoing issue is attributed to long-standing structural factors such as insufficient capacity and recent behaviors like overordering and stockpiling by automotive companies.

**Challenges in Addressing Mature Node Shortages:** For semiconductor nodes greater than 90 nanometers, which are in high demand in the automotive industry, the shortage is likely to persist due to low-profit margins associated with these mature nodes and limited incentives for end customers to migrate to lower node sizes [31]. This is compounded by the additional development and qualification costs and the limited availability of R&D staff.

These factors collectively highlight the multifaceted impact of the semiconductor chip shortage on the EV industry, underscoring the need for strategic adaptations and resilience-building measures to navigate these challenges effectively.

**4.4 Toward a Sustainable Solution**

A comprehensive and multifaceted strategy is essential in addressing the challenges posed by the semiconductor chip shortage, particularly in the electric vehicle (EV) industry. This approach should focus not only on immediate mitigation but also on building long-term resilience and sustainability within the supply chain. In the short term, measures like establishing control rooms for coordinating procurement, supply chain management, and sales efforts have shown efficacy. However, these solutions need to be part of a broader, strategic approach aimed at addressing medium to long-term challenges. A range of proposed multifaceted solutions[28], aimed at addressing the challenges and complexities outlined in the previous section is presented below. These solutions are designed to tackle the semiconductor chip shortage that has significantly impacted the electric vehicle (EV) industry and its associated supply chain.

**Diversification of Suppliers:** One critical aspect of this strategy involves diversifying suppliers. By reducing reliance on a single supplier, the automotive industry can mitigate the risks associated with supply chain disruptions. This approach spreads the risk and ensures a more stable supply chain, even during unexpected crises.

**Investment in Domestic Production:** Another significant measure is the investment in domestic semiconductor production. This initiative aims to strengthen supply chain resilience by reducing dependency on global sourcing. Local production can offer more control and quicker response times in addressing supply chain issues.

**Collaboration and Communication:** Additionally, enhancing collaboration and communication among key stakeholders, including semiconductor manufacturers, automotive companies, and governments, is crucial for proactively addressing potential challenges. Such collaborative efforts can lead to more cohesive strategies and quicker adaptations to changing market conditions.

**Strengthening Technology Roadmaps:** Central to this strategy is the need to define actual semiconductor dependencies and ensure comprehensive technology roadmaps [32]. A clear understanding of these dependencies will allow for better planning and allocation of resources.

**Improving Short and Long-term Demand Planning:** Improving short-term demand planning is also essential. OEM providers need to enhance their transparency and communication with semiconductor vendors to better predict and fulfill their immediate requirements. Furthermore, collaboration on investments in semiconductor development for
advanced nodes is vital. This collaboration is key to balancing the costs and driving innovation in semiconductor technology[32].

The Indian automotive sector serves as an example of industry adaptation in response to the chip shortage. Automakers in India have resorted to producing vehicles with reduced chip usage to mitigate the impact of the shortage [33]. Moreover, long-term strategies must intertwine supply chain security with environmental sustainability. The semiconductor industry is urged to adopt cleaner production methods and embrace a circular economy model. Such approaches are necessary to address not only the shortages but also to ensure environmental compliance [34].

Tesla’s approach during the chip shortage, including internal chip production and software flexibility, offers valuable lessons in effective chip management. Additionally, innovations like AI-designed chips could potentially revolutionize chip production and alleviate supply chain bottlenecks. Proactive strategies, such as leveraging data analytics and fostering collaborations, are being increasingly adopted by businesses to mitigate risks [35].

In conclusion, the semiconductor chip shortage has underscored the critical need for a comprehensive understanding of supply chain vulnerabilities and the development of robust, resilient solutions. This paper has provided a thorough examination of the semiconductor chip shortage and its multifaceted impact on the electric vehicle (EV) industry, from its origins to its wide-reaching consequences. Starting with an exploration of Silicon Carbide (SiC) semiconductors and their critical role in advancing EV technology, we delved into the complex interplay of factors that led to the chip shortage, including the disruptions caused by the COVID-19 pandemic and the intricate dynamics of the global supply chain. The paper then highlighted the significant implications of this shortage for the EV industry, including production delays, increased vehicle costs, and broader impacts on the automotive ecosystem. Finally, we proposed a multifaceted and sustainable approach to address the shortage, emphasizing the importance of supplier diversification, domestic production, enhanced collaboration, and the adoption of innovative technologies like AI-designed chips. By synthesizing these insights, the paper underscores the urgency for strategic adaptations and resilience-building measures, ensuring that the EV industry can navigate current challenges and prepare for future disruptions effectively.

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mismatch-persist-for-automotive-semiconductors


