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Review scientific paper

Modern Semiconductors in Military and Defense Industry Applications

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ABSTRACT

The modern military and defence industry is heavily dependent on semiconductor devices. This paper will provide a brief overview of the military application of semiconductor devices, outline their design and manufacturing requirements, and discuss supply chain considerations. Special focus will be placed on highlighting the challenges of modern packaging applications in the military and defence industry, ensuring products meet the required reliability and security specifications. Additionally, the importance of securing a steady supply of devices for national security considerations will be discussed. The paper aims to provide an overview of the most common types of military semiconductor devices, their role and future technology developments.

KEYWORDS: *military semiconductors, reliability, manufacturing, supply chain, semiconductor trends*

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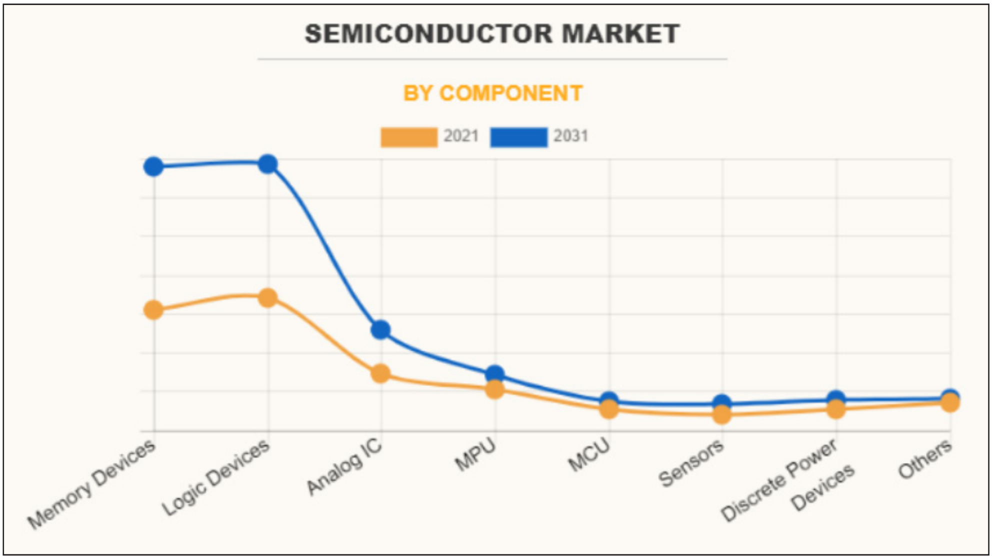
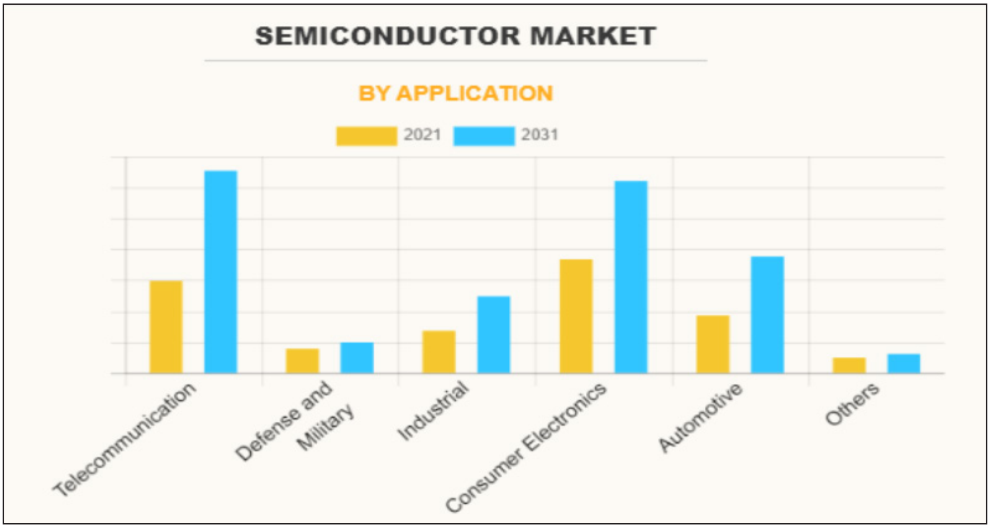
Introduction

Semiconductors can be divided into logic, memory and other devices. Logic devices are composed of computational and graphics processing units (CPUs and GPUs, respectively). Memory devices consist of read-only memory (ROM), which is non-volatile, and random-access memory (RAM), which is volatile. The other group comprises discrete, analogue, and optoelectronic devices. Logic and memory devices dominate the semiconductor market (Figure 1). The technical specifications and use of each device's subgroup vary by application. The military and defence industry utilises devices across all three high-level subgroups, including radars, satellites, unmanned vehicles, precision targeting systems, sensors, actuators, and onboard computers (Pathan et al., 2024). Even though the defence semiconductor market segment is not a key driver of the industry (Figure 1b), it remains of great importance for national security and is increasingly an asset in diplomatic negotiations. The total available market for military semiconductor devices was 23 billion USD and is projected to reach 55 billion USD in 2032, based on a 2023-2032 analysis (Global Market Insights, 2023).

Figure 1: Comparison of Semiconductor Market Segments: 2021 and 2031 Forecast



a) Breakdown of semiconductor market by component type



b) Breakdown of semiconductor market by application

Note. (a) Breakdown by component type; (b) breakdown by market segment. Reprinted from Upadhaya et al. (2022).

One key characteristic of military semiconductor devices is their need to be reliable in the field. Failure to do so comes at the high price of lost human lives. To address this concern, devices are designed leveraging older silicon (Si) wafer technology process nodes, as they are higher-yielding and more reliable. (Pathan et al., 2024). Additional economic benefits of choosing a more established process node include manufacturing facilities that are fully depreciated, thereby reducing manufacturing costs. Newer Si process nodes are needed to enable advanced artificial intelligence (AI) capabilities and offer improved performance in the field. Additional considerations for military and defence devices are the extreme environmental conditions they must withstand, such as high temperatures, pressures, winds, low or no light, radiation, and shock. Under those extreme conditions, defence semiconductor products must be effective, reliable, tamper-proof, fast-communicating, easily maintainable, and manufactured cost-effectively (Gargeyas, 2022).

The use of wide-bandgap wafer materials (silicon carbide and gallium nitride) can provide higher thermal stability, greater power efficiency, more compact dimensions, and higher-frequency switching. (Aborah Yeboah et al., 2025; Buffolo et al., 2024; Kolawole, 2025; Masoud Beheshti, 2020; Pathan et al., 2024). Compared to silicon, gallium nitride (GaN) and silicon carbide (SiC) have wider band gaps and superior electron mobility, enabling semiconductor devices to withstand higher electric fields before breakdown and to switch faster, respectively. (Kolawole, 2025) as shown in Table 1. Additionally, they have a wider thermal operating range (temperature sensitivity shown in Table 1), enabling sustained performance under extreme temperatures. The disadvantages of SiC and GaN wafers lie in the complexity of their manufacturing, which makes the process more costly and limits their widespread application. Innovation in manufacturing techniques and materials will enable greater applicability as process costs and yields improve. (Amano et al., 2018). Nonetheless, the adoption of GaN in the military and defence industry is strong due to the improved technical performance. The ability to operate at higher voltages and frequencies without detriment enables use in power electronics and communications (5G, RF, and radar). The high thermal conductivity of SiC makes it favourable for use in high-temperature and high-power applications, as well as in the electric vehicle industry.

Table 1. Comparison of properties of semiconductor wafer materials

GaN vs SiC vs Si Comparison			
Property	**Silicon (Si)**	**Silicon Carbide (SiC)**	**Gallium Nitride (GaN)**
Energy Band Gap	1.1 eV	3.2-3.3 eV	3.4 eV
Temperature Sensitivity	150°C max operating	200°C+ operating range	200°C+ operating range
Electrical Conductivity	1450 $cm^2/V·s$ (electron mobility)	650-900 $cm^2/V·s$ (electron mobility)	1500-2000 $cm^2/V·s$ (electron mobility)
Thermal Conductivity	150 W/m·K	490 W/m·K	130 W/m·K
N-Type Doping Capability	Excellent (phosphorus, arsenic)	Good (nitrogen)	Excellent (silicon)
P-Type Doping Capability	Excellent (boron)	Challenging (aluminium)	Difficult (magnesium)

Electron Mobility	1450 cm^2/V·s	650-900 cm^2/V·s	1500-2000 cm^2/V·s
Relative Cost	Low (baseline)	Medium-High (3-5x Si)	High (5-10x Si)
Availability	Excellent	Good	Growing
Best Applications	General-purpose electronics, low-power devices	High-power, high-temperature applications	High-frequency, high-efficiency power conversion

Note. Adapted from Component Parameters & Applications (2025).

All three wafer materials listed in Table 1 are used in military and defence semiconductor devices. They address different technical requirements for different device types and applications.

Military and Defense Semiconductors

In this paper, only some of the most prominent semiconductor devices used in the military and defence industries are presented: sensors, logic FPGA devices and memory. Focus will be on typical use cases and component requirements, as well as considerations for key future technology development trends.

Sensors

Sensors used in military applications are widespread. Some examples include identifying and disposing of targets, improving situational awareness, and monitoring changes in environmental conditions that affect vehicles and soldiers' physiological states (Gargeyas, 2022; Nayak et al., 2023; Shaw & Harrell, 2023). Sensors improve performance on the battlefield by aiding military personnel's decision-making under significant physical and psychological stress, ensuring high-quality data-driven decisions are made in the field.

General requirements for sensors are that they maintain their placement when in use, are resistant to tampering, have rapid and secure data communication with a sufficiently large communication range, are cost-effective, have tolerable physical dimensions and weight to the system, ideally with small electromagnetic emissions, are energy efficient and are integrable with many different types of wireless sensors in the network. (Đurišić et al., 2012). Sensors can be divided into eight categories: radar, infrared, acoustic, electro-optical, magnetic, biochemical, light detection and ranging (lidar), and quantum sensors. Table 2 highlights the operating mechanisms of different sensor types and some of their key applications.

Table 2. Breakdown of defence sensor types, their operational mechanisms, and military applications.

Sensor type	Operation mode	Application
Radar	Transmitting pulses and capturing the reflection of radio waves	Air defence systems, missile guidance, and perimeter security
Infrared	Detect heat signatures	Surveillance, night vision, and targeting systems
Acoustic	Capture sound waves	Help detect and classify threats on the battlefield
Electro-optical	Converting light (or changes in light levels) into electronic signals	Detect electromagnetic radiation to find and track objects across the spectrum missile guidance, reconnaissance, and surveillance drones
Magnetic	Detect changes in magnetic fields caused by metallic objects	Submarine, landmine and vehicle detection; navigation and positioning when GPS is unavailable
Biochemical	Detecting chemical or biological agents in the surroundings	Mapping chemical and biological threats
Lidar	Transmitting pulses and capturing the reflection of lasers	Mapping of the battlefield Virtual reality/Augmented reality training
Quantum	Leverage quantum mechanical phenomena for accurate mapping	Underwater surveillance, navigation

Note. Adapted from Sumaria (2025).

In an effort to ensure human lives are protected, and the quality of decision making is high, the military and defence industry continues to network large systems of interconnected devices (Internet of Things (IoT))- where a multitude of different sensor device types are used. The use of interconnected devices enables smart, efficient, and fast decision-making systems. It also allows for improved logistics and supply chain management, ensuring that the correct resources are deployed in the needed locations at the right time (Nayak et al., 2023). As the use of interconnected systems expands with more and more devices, so does the need for faster, more efficient communication channels between them (driving the adoption of faster networking technologies like 5G and 6G). Additionally, as all of the data collected by the various sensors needs to be processed by a logic device, greater performance logic devices continue to be needed.

Logic devices

Field-programmable gate arrays (FPGAs) are among the most commonly used logic devices in military and defence applications. These semiconductor logical circuits enable real-time, high-performance, and low-cost systems (Saday, 2022). They contain configurable logic blocks (CLBs) that can be configured to perform specific functions. Programmable interconnects connect the different CLBs, enabling low-latency signal transfer between them. Unlike traditional CPU and GPU devices, FPGAs are programmable, typically of low power consumption and with high computational capacity (Saday, 2022). Properties that make FPGAs suitable for military applications are their reconfigurability, radiation resistance, fast and secure processing of large data sets, making them suitable for image processing applications, communication systems, electronic warfare and other military uses (Saday, 2022).

Design and manufacturing of FPGA devices is complex, resulting in a high initial product cost, but a lower total lifetime cost due to their re-programmability in field. There is a growing demand for FPGA parts, as they are used across all high-growth semiconductor market segments, including high-performance computing (AI and machine learning (ML)), telecommunications, and IoT. Globally, two manufacturers hold the majority of the FPGA market: AMD (after the purchase of Xilinx) and Altera (previously owned by Intel Corporation) (Saday, 2022). For national security reasons, the military and defence industry may have priority in obtaining parts during periods of higher demand than manufacturing capacity can meet. However, to avoid such scenarios, proper supply chain planning and ensuring that general-use parts are suitable for military and defence industry applications and carry appropriate certifications are paramount.

Memory

Another vital component to ensure properly functioning and reliable systems are memory devices. Many different types of memory devices are used in numerous products to store data either permanently or temporarily. Low latency of data communication to and from the memory is crucial to ensure fast and reliable communication between the complex integrated systems, like those of wireless sensor networks (Sañudo et al., 2020). Military and defence applications benefit from using non-volatile memory, ensuring data is not lost when the memory is powered off. In addition to non-volatile, volatile RAM-type memory applications in defence are also common (Infineon, 2025). Independent of the type, memory devices used require physical and functional durability when exposed to challenging environmental conditions for quality performance (Gargeyas, 2022). High-reliability memory devices require special certifications and are used in communications, GPS equipment, ground-based radar, flight recorders and other applications.

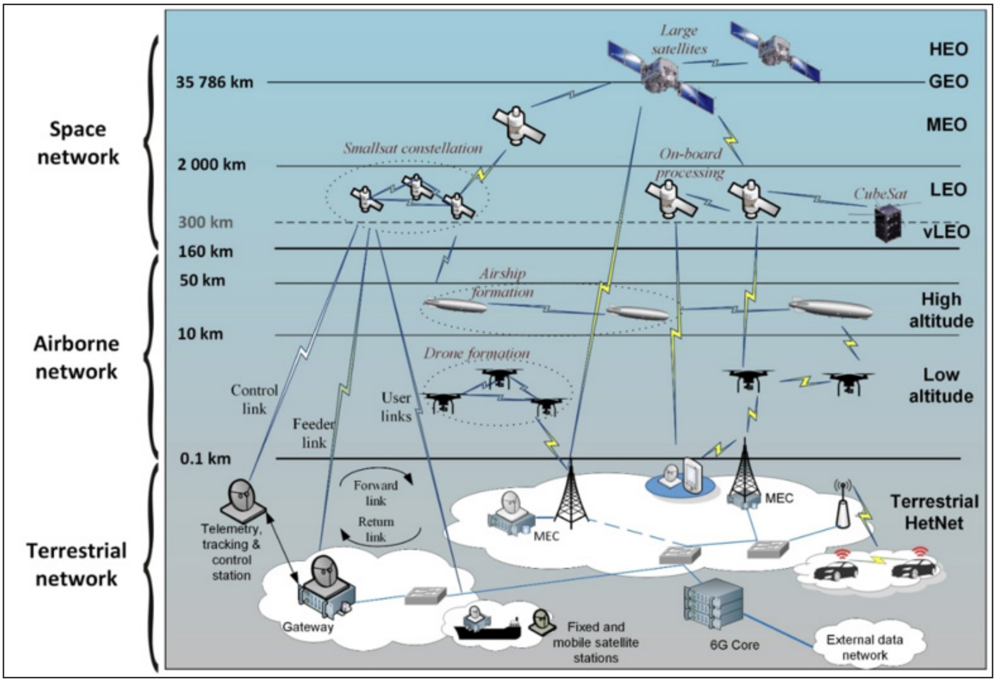
Future considerations

Future technology development areas for the military and defence industry will focus on enabling 5G and 6G communications, greater use of AI, and the integration of a wide array of connected devices.

The ability to track different assets, man-made and human resources, is important for the military and defence industry to ensure asset safety, recoverability, and optimise logistics and decision-making in real time. As the number and variety of interconnected semiconductor devices continue to grow, the need for reliable, fast communication grows. The need to enable direct, fast Machine-to-Machine (M2M) communication is the driver behind the implementation of 5G and 6G networks. Enablement of 5G in military applications will benefit from lower latency of signal, higher reliability and security (Bastos et al., 2020; Miličević & Bojković, 2024). Additionally, it provides a pathway for implementing AI and machine learning.

AI devices with 6G technology will enable more efficient, faster communication and data processing of large datasets generated by heterogeneous networks of diverse communication devices and scenarios, leveraging a greater number of antennas and wider bandwidths (Abdel Hakeem et al., 2022). Additionally, 6G technology will enable integrated, all-terrain, multilayer communications (as shown in Figure 2), with new radio bands that will improve communication capacity and data speeds and enhance security and privacy (Abdel Hakeem et al., 2022; Miličević & Bojković, 2024).

Figure 2: Representation of multi-terrestrial communication with 6G technology



Note. Reprinted from Wang (2023).

The AI-enabled technology allows for predictive maintenance, threat detection, and autonomous decision-making (Bhatia & Pallvi, 2025). To enable AI use, greater adoption of newer process technology nodes is expected, which will trigger additional testing during manufacturing to ensure devices sent to the field meet military standards. Heavy capital investment is expected for the adoption of AI (Pathan et al., 2024). Countries with clear AI implementation strategies will benefit by ensuring they are not at a technical disadvantage and that they have a fully capable military and defence ecosystem ready for potential conflicts with the most technologically advanced foes. A comprehensive strategy would encompass ensuring that all resources are available at military-standard quality and that a highly reliable supply chain supports all components and software needed to achieve the national defence strategic goals.

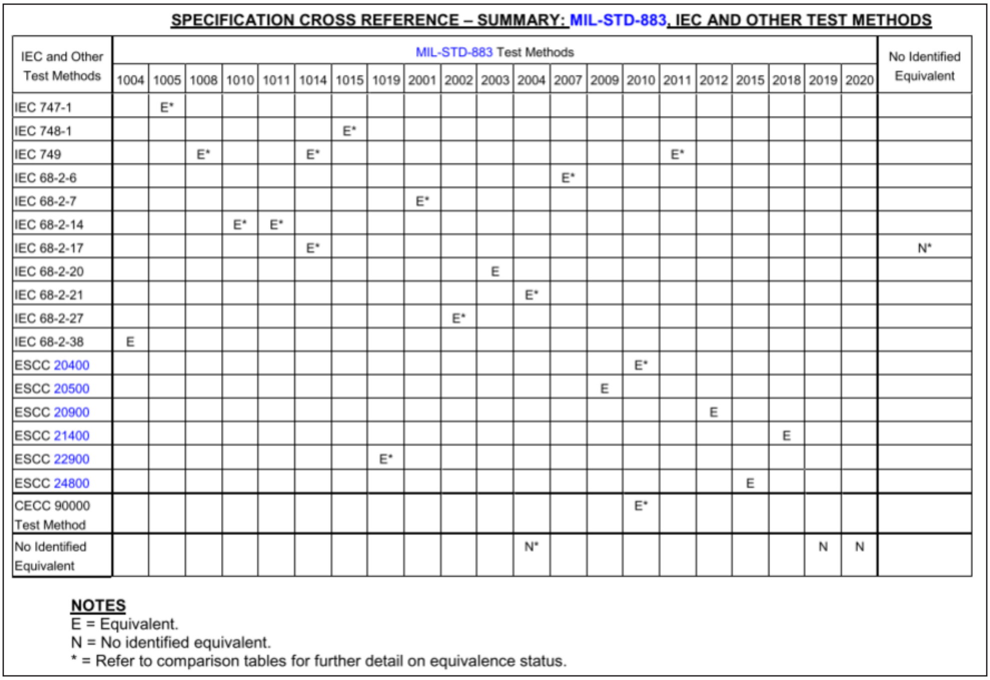
Considerations for Reliable Supply

Quality and Reliability requirements

Military semiconductor devices must meet specific technical specifications to operate under extreme environmental field conditions. Those conditions include high temperature, humidity, vibration, radiation and long operating hours. Additionally, the service life of military components exceeds that of commercial parts. (Biddle, 1996). It is imperative that these parts are defect-free, as lives depend on them. To ensure this is met, in addition to designing chips on older, more reliable process nodes, military technical specifications must be followed during manufacturing. Only those manufacturing suppliers and facilities, and parts that comply with their requirements, are included in the list of qualified products (QPL) and manufacturers (QML) for military applications (Pecht et al., 1997; Yarbrough et al., 2020). Different nations have different governing standards for the electrical, electronic, and electromechanical (EEE) components. In the United States (US), military performance standards (MIL-PER) and military standards (MIL-STD) are followed. In the European Union (EU), the European Space Components Coordination (ECSS) is responsible for EEE specifications and preferred products and suppliers' lists. The European Space Agency (ESA) governs ECSS, and Croatia became an ESA cooperating state in 2023. Additionally, the International Electrotechnical Commission (IEC), of which Croatia is a full member state, has its own set of standards for EEE. There are additional governing standards that specify how circuits, components and devices should be manufactured.

The above-noted military standards are sets of specifications for products and services used by the military, which allow those products to be deemed ready for military and defence use. An example of the comparison of different global standard specifications is shown in Figure 3 for the MIL-STD-883 standard, one of the key standards used for microcircuit test methods. Special certifications required to qualify a component for the QPL drive up the cost of parts used in military and defence applications. Due to the strict technical requirements, commercial parts that may have the same performance ratings, if not manufactured and tested per the required military standards, are not to be used in the military and defence applications (Pecht et al., 1997). Sourcing parts cross-referenced to another national standard can be an efficient way to ensure a healthy supply chain for semiconductor components sourced outside the national QPL while still meeting all national standard specifications. The complete list of standards that a semiconductor device needs to meet will depend on its final application, manufacturing process, and the materials and components used in its construction.

Figure 3: Cross-reference of European and United States military standards



SPECIFICATION CROSS REFERENCE – SUMMARY: MIL-STD-883, IEC AND OTHER TEST METHODS

IEC and Other Test Methods	MIL-STD-883 Test Methods																					No Identified Equivalent
	1004	1005	1008	1010	1011	1014	1015	1019	2001	2002	2003	2004	2007	2009	2010	2011	2012	2015	2018	2019	2020	
IEC 747-1		E*																				
IEC 748-1							E*															
IEC 749			E*			E*										E*						
IEC 68-2-6													E*									
IEC 68-2-7									E*													
IEC 68-2-14				E*	E*																	
IEC 68-2-17						E*																N*
IEC 68-2-20											E											
IEC 68-2-21												E*										
IEC 68-2-27										E*												
IEC 68-2-38	E																					
ESCC 20400															E*							
ESCC 20500														E								
ESCC 20900																	E					
ESCC 21400																			E			
ESCC 22900								E*														
ESCC 24800																		E				
CECC 90000 Test Method															E*							
No Identified Equivalent												N*								N	N	

NOTES
E = Equivalent.
N = No identified equivalent.
* = Refer to comparison tables for further detail on equivalence status.

Note. Reprinted from European Space Components Coordination (2014)

Supply chain considerations

Semiconductor devices are complex integrated systems of many components. Ensuring components are available for the product's useful life is paramount. Military devices share components with non-military application devices. (Microchip USA, 2025a). For national security reasons, it is paramount that defence forces have a reliable supply chain for all components of military-approved devices. (Sultan & Sultan, 2024). Geopolitically, most of the semiconductor devices are manufactured in Southeast Asian countries. Even with the European Union's Chips Act initiatives, it is not feasible to ensure the supply chain of all types of components (Microchip USA, 2025b; Pathan et al., 2024). Therefore, many countries have realised the importance of maintaining a sufficient, readily available supply when needed. (Arjunamahanthi et al., 2025; Bonheim et al., 2003). Failure to do so could result in assets being out of commission and weakened national defence positions.

In order to overcome the supply chain constraints, a country can: a) manufacture their own components, b) stockpile components from allies that are of national interest for the military, and c) negotiate support with allied nations to source qualified parts when needed. Manufacturing independence is an expensive proposition and not feasible unless a reliable supply of raw materials, equipment, and manufacturing facilities is available from the ingot stage through the final packaged device stage. The United States and the European Union have agreed to support national semiconductor manufacturing through the US and EU Chips Acts, respectively. These investments are strategic and do not address current supply chain constraints, in which both the US and the EU rely heavily on Asian partners for semiconductor devices, components, and materials (Microchip USA, 2025a; Pathan et al., 2024).

The other two proposed avenues are more feasible, and many governments are enhancing supply chain resilience by investing in semiconductor companies (as in the USA government's funding of Intel Corporation in 2025) or by stockpiling parts. To ensure supply chain continuity, it is important to cross-reference the equivalency of military standards with other standards agencies, such as the Automotive Electronics Council (AEC) (Yarbrough et al., 2020), to open equivalent supply-chain avenues. It is paramount that cross-references to component equivalencies are available and up to date, as standards are regularly updated by their governing agencies. Resilience in the supply chain needs to be ensured to maintain national security. The military industry does not necessarily have priority over consumer electronics, since its market share is low relative to other sectors (Figure 1b). This becomes a potential chokehold, especially when advanced technologies are required, as capable manufacturing facilities are in short supply and in high demand globally.

Conclusion

The use of modern semiconductors will remain paramount in the military and defence industry. Semiconductor devices and the ecosystem are critical components for ensuring robust national security. The design of military devices must keep pace with the latest technologies to ensure adversaries do not gain a competitive advantage. The drivers for growth will be enabling compact, easily maintainable, reliable, high-performing, fast-decision-making, and secure devices. With the increasing number of interconnected device types, improvements in parts' performance, inter-part communication, and computational performance are expected to enable fast, efficient decision-making that will provide a technological advantage on the battlefield. Continued strategic investments in the military-based semiconductor device sector are needed. These investments will drive advancements ranging from novel design capabilities to processes and materials that improve manufacturing capabilities and yields. Novel design capabilities will allow for the implementation of AI and the latest communication techniques. New processes and materials will help reduce manufacturing costs and the complexity of manufacturing processes. New testing processes will be needed to ensure the devices adhere to strict standards and specifications, ensuring reliable, high-quality parts that withstand extreme conditions, are tamper-resistant, and deliver defect-free performance.

Short-term, to maintain the existing fleet of military and defence semiconductor devices, the supply chain of critical components should be assessed to ensure reliable national stockpiles of QPL parts for the service life of critical devices. Failure to do so can result in the grounding of key assets and the inability to perform national security duties. In addition to capital investments, strategic investments in developing human resources to maintain and drive technological advancements are paramount. National governments should work with academia to ensure talent is familiar with the latest technologies and skilled to work in the fast-developing semiconductor ecosystem. Ultimately, those nations that ensure strong capabilities with modern military semiconductors will have a very strong negotiation position in the ever-changing geopolitical arena.

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Moderni poluvodički uređaji u vojnoj i obrambenoj industriji

SAŽETAK

Moderna vojna i obrambena industrija uvelike ovisi o poluvodičkim uređajima. Ovaj rad pruža kratak pregled vojne primjene poluvodičkih uređaja, opisuje njihove odrednice za dizajn i proizvodnju, te specifičnosti opskrbnog lanca. Poseban naglasak stavljen je na isticanje izazova modernih primjena poluvodičkih uređaja u vojnoj i obrambenoj industriji, osiguravajući da proizvodi zadovoljavaju potrebne standarde pouzdanosti i sigurnosti. Nadalje, opisana je važnost stabilnosti opskrbnog lanca poluvodičkih uređaja zbog nacionalne sigurnosti. Cilj rada je pružiti pregled najčešćih tipova vojnih poluvodičkih uređaja, njihove uloge i budućih trendova tehnoloških razvoja.

KLJUČNE RIJEČI: *vojni poluvodiči, pouzdanost, proizvodnja, opskrbni lanac, trendovi poluvodiča*