Emerging Technologies

Developments in the Context of Dual-Use Export Controls

Factsheets

Following an initiative of the Romanian Presidency in 2019, the Commission invited Member States to participate in informal emerging technology workshops. Five workshops were organised from November 2019 to November 2020, covering a range of emerging technologies, such as quantum computing, additive manufacturing, artificial intelligence, brain-computer interfaces, special materials, advanced semiconductors, hypersonics.

As a result of the workshops, during the German Presidency, experts compiled a series of "Fact sheets" providing summary information for each relevant emerging technology (See Annex).

Data analytics and Advanced Computing
Fact Sheet

TRL

Industry:
Commercial and open source software

Science:
Basic and applied research

General Information

Data analysis (***advanced computing***) is an important part of artificial intelligence. It describes the intelligent processing and evaluation of large and unstructured amounts of data (***big data***) using statistical or semantic methods. The end result are relevant data sets (***smart data***) that can be used for further work.

Often, the intent is to not only examine and evaluate simply past events. Rather, the goal is to use data mining, machine learning and other statistical methods to make predictions about the probability of future events (***predictive analytics***).

The data analysis uses known algorithms that are trained for a specific task using expert knowledge and special data.

The quality of the results depends heavily on the amount and quality of the input data. The way the solution that has been reached is partially invisible, which makes it a great challenge to explain the results.

Technological fields

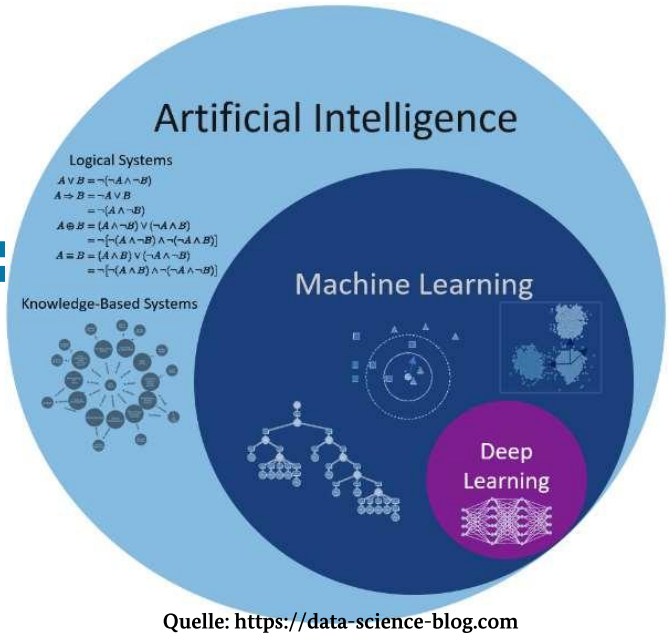
- **Artificial neural networks (ANN)** are networks of artificial neurons and consist of a large number of layers. In these, predictable behavior is "trained" through weighting and feedback and improved with each new run.
- **Machine learning** is a self-adaptive algorithm, i.e. the computer system learns independently based on the available data. **Deep learning** is a subset of machine learning and uses many hierarchical layers to carry out the machine learning process.
- **Text mining or data mining** is the algorithm-based, systematic application of statistical methods to large volumes of text or data with the aim of discovering existing patterns and predicting new trends (***predictive analytics***).
- **Semantic technologies** aim at an actual understanding of the meaning, which is often made difficult by multiple meanings, ambiguity, or the unknown.
- **Cluster procedures** (clustering algorithms) are used to find similarity structures in large amounts of data.
- **Decision tree methods** are used for classification or regression or for automatic optimization.

Data analytics and Advanced Computing
Fact Sheet

Industry Sectors

Industries:
- As data analysis is an important part of AI, it is used in the background in all industries

Fields of Application:
- Simulations, e.g. development of new materials or retrosynthesis proposals for chemicals
- Forecasts on weather data, population developments, etc.
- Autonomous driving and flying
- Intelligent assistance systems
- Optimized resource management
- Optimized logistics systems
- Quality control, process and component optimization
- Knowledge management / expert systems



Quelle: https://data-science-blog.com

Export control relevant Applications

Military:
- Autonomous weapon systems
- AI supported warfare systems
- Reconnaissance & target identification
- Automatic hazard detection
- Military logistics & transport planning

Public security agencies:
- **Cyber attacks & defence:** detection of attacks aon networks, early warning systems
- **Internal repression / surveillance:** evaluation of communication, voice and face recognition, Predictive Policing

Current Listings

- Hardware for neural networks, e.g. CPUs, FPGAs, ASICs, is included in category 3. In line with US, the controls appear sufficient.
- Sensors for image recognition (visible, IR, UV, radar), sound, gravity and pressure can be found in Category 6, those for toxic gases in Category 2

Advanced Materials
Fact Sheet

General Information

Advanced materials are those materials in which specific properties of the material (e.g. tensile strength, absorption behaviour, conductivity, resistance, weight) have been particularly improved.
Advanced materials are used in the fields of pharmacy, medicine, biology and as technical materials for electronics, energy and component manufacturing.

The research and development of modern materials can largely be ascribed to materials science. This discipline makes use of the fundamental knowledge from the fields of chemistry and physics. Closely linked to this is materials technology, which deals with the production of components and includes elements of process, construction and manufacturing technology.

Technology fields

- **Cloaking devices** – Adaptive Camouflage and other functional textiles: the generic term cloaking devices includes among others:
  - "Adaptive camouflage" (reproduction of the background image or another image, which leads to the camouflaging of an object or to deception)
  - Metamaterials (material with a negative index of refraction, change in the incident light and thus masking out objects)
  - Nanomaterials, e.g. on the basis of carbon derivatives (e.g. carbon nanotubes, "Vantablack", with almost complete absorption of incident light, whereby the actual dimensions of an object can no longer be visually determined).
- **Advanced Fibre and Fabric Technology**: inter alia, carbon fibres, which, as reinforcing fibres, particularly increase the strength values of the composite material. Areas of application include armouring (energy dispersion), rotor segments of ultracentrifuges.
- **Nanomaterials**: cross-sectional technology, wide range of materials, as the definition is not clear (related to dimensions). These include e.g. carbon-based systems (graphene, carbon nanotubes), MOFs, quantum dots and a large number of other organic and inorganic representatives, in the form of nanoparticles, layers (2D materials) / coatings, nanowires / nano-conductor tracks. Also interesting in connection with process engineering (coating technology).
- **High-entropy alloys (HEA):** new class of metallic materials, which are composed of at least 5 elements. First approaches give an idea that the HEA should be able to exhibit extraordinary properties (high temperature behaviour, density, superconductors) in the future. At the moment, however, the topic is focused on fundamental issues. A rapid breakthrough is currently not foreseen.

Advanced Materials
Fact Sheet

Industry Sectors

Modern -materials and nanomaterials are already being used in a wide variety of fields.

- **Chemistry:** effective pigments, ferrofluids, polymer dispersions, semiconductors, polymer composites, nanopowders, new metals, lightweight construction materials
- **Automotive:** catalytic converters, nano-coatings, tire additives, diesel additives, lightweight composites
- **Electronics:** hard disk / flash memory, MEMS memory, silicon / polymer electronics, displays
- **Medicine/pharmaceuticals:** contrast media, drug carriers, biochips, nanoprobes / markers, biocompatible implants
- **Optics:** LED/OLED, diode laser, nano-layers (anti-reflective coating, scratch resistance), ultra-precision optics
- **Energy- and environmental technology:** catalysts, air / waste water purification, heat protection (turbines), batteries
- **Mechanical engineering, construction:** switchable glasses, aerogels (insulation), seals / coatings (heat protection), (fibre)reinforced components
- **Textile industry:** clothing (dirt-repellent, antibacterial, UV protection, thermal protection), technical textiles
- **Security technology:** banknotes, decontamination systems, detection (e.g. electronic noses), diagnostics

Export control relevant Applications

Military:

- Materials for camouflaging soldiers, tanks and equipment in action (adaptive camouflage, metamaterials)
- Reinforcement materials for special parts, e.g. rotor segments for centrifuges, particularly resistant components / armouring, etc. for ballistic and tactical missiles
- Growing, self-healing (e.g. vitrimers) and self-destructing (also: "transient") materials
- Novel materials (lightweight construction materials and composites) and innovative substances (e.g. MOFs as explosives)
- Detection, diagnostics and decontamination in the CBRN area and for explosives

Public security agencies:

- Detection, diagnostics and decontamination for CBRNE (civil and disaster control/protection)
- Reinforcement materials for many areas and various industrial goods, e.g. in the automotive sector or in aircraft construction or for pressure vessels, flywheels, tubular structures etc.

Current Listings

List entries already exist for certain relevant goods in the EC Dual Use Regulation or in the export list: e.g. 1C001 or 1C101 (materials or materials specially developed for the absorption of electromagnetic radiation), 1C010 or 1C210 (fibrous or filamentary materials), A0007.f / 1A004 detection equipment.

In some cases, individual topics for which there are no list items are debated in the export control regimes on a scientific and technical level. In many cases, however, significant relevance for export controls cannot be determined or only in the most distant sense, which is why detailed discussions about new list proposals are not useful and therefore do not take place.

AI – Artifical Intelligence

Fact Sheet

General information

Artificial Intelligence (AI) is a sub-field of computer science that deals with the automation of intelligent behaviour and machine learning. AI intents to imitate certain decision-making structures of the human brain by, for example, structuring and programming a computer in a way that it can work on problems relatively independently. One can distinguish narrow and general AI.

The **narrow (weak) AI** usually deals with the solution of specific problems through the simulation of „intelligence“ via instruments of computer science and mathematics. Often these are optimization problems based on large amounts of data (big data). All of the technology fields mentioned below concern narrow AI.

General AI, on the other hand, is the form of artificial intelligence that has the same intellectual abilities as humans or even goes beyond it. It still requires a lot of research to achieve the envisioned goal: establish general statements and be able to build a stable and independent unit based on these. One difficulty that has to be overcome in the process is to provide the unit with a basic understanding of the world, some kind of common sense.

TRL

Industry: Research projects and first introduction in sub-areas, already some products with narrow AI on the market

Science: Basic research and applied science

Technology fields

- **Knowledge-based systems:** so-called expert systems. System provides answers to a user question based on formalized specialist knowledge and the logical conclusions drawn thereof.
- **Image recognition and understanding:** AI enables the recognition and analysis of images, objects and shapes.
- **Data management and data analytics:** Analysis of large, complex or poorly structured data basis.
- **Robotics and autonomous systems:** Human behaviour shall be imitated by robots.
- **Sensor technology and communication:** data generated by one or different sensors are combined and evaluated quickly, outcome has an impact on sensor settings to predict certain events
- **Language and text comprehension**: Written text can be transformed in language and vice versa. Latent semantic analysis (LSI) provides meaning to words and text.
- **Virtual and augmented reality:** supports Human-Machine-Interaction and Human-Machine-Interfaces.

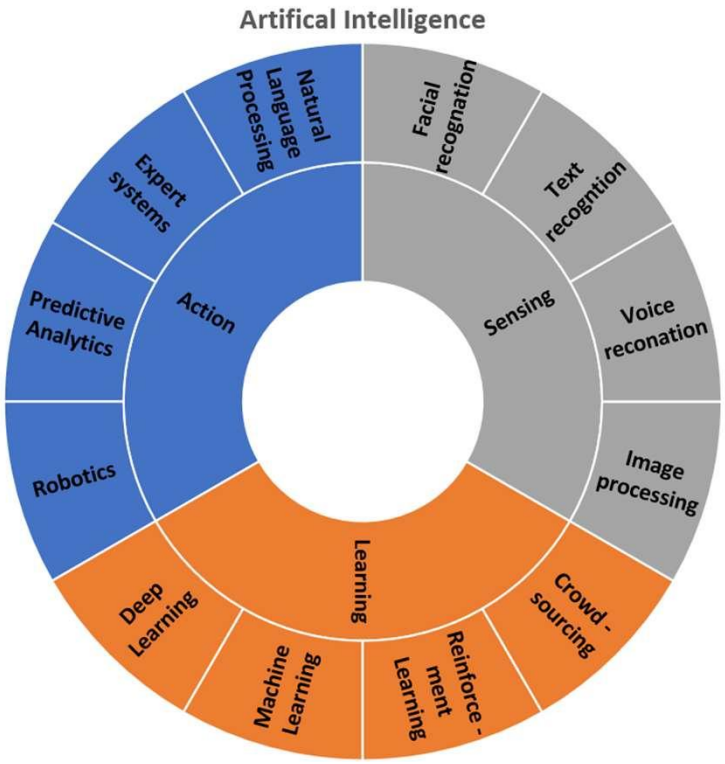
AI – Artifical Intelligence
Fact Sheet

Industry sectors

Sectors:
- AI is applied cross-sectoral

Applications are:
- Autonomous driving and flying
- Intelligent assistance systems
- Optimized resource management
- Quality control
- Industry 4.0
- Knowledge management
- Robotics
- Automation in general
- Data analysis and management

Areas of narrow AI



Export control relevant applications

Military:
- Autonomous weapon systems
- AI supported warfare systems
- Reconnaissance & target identification
- Automatic hazard detection
- Military logistics & transport planning

Public security agencies:
- **Cyber attacks & defence:** autonomous attacks by self-learning systems, autonomous detection of attacks on networks.
- **Fake news:** e. g. through speech or identity manipulation, targeted influence through propaganda.
- **Internal repression, surveillance:** analysis of vocal communication, facial recognition.

Current listings

AI is based on publicly available algorithms that are trained for a specific task using expert knowledge and specific data.
Proximity exists to the following listing positions of the dual use regulation:

- Hardware for neuronal networks, e.g. CPUs, FPGAs, ASICs, are included in category 3.
- Sensors for image recognition (visible, IR, UV, radar), sound, gravity and pressure can be found in category 6, those for toxic gases in category 2.

Additive Manufacturing
Fact Sheet

General Information

„3D printing" is a comprehensive term for all additive manufacturing processes, whereby the term "3D printing" is often used as a synonym for additive manufacturing. Additive manufacturing is a professional production process that differs significantly from conventional, abrasive manufacturing methods. For example, instead of milling a workpiece out of a solid block, additive manufacturing builds up components layer by layer from materials. Material is fused layer by layer and three-dimensional components are created. Liquid or solid (mostly powder or wire) materials made of metal or plastics are used as starting materials, and in some cases ceramics.

The additive manufacturing processes have their origins in prototype construction and have become known as rapid prototyping, as they can be used to quickly manufacture sample components. This means that additive manufacturing processes offer another manufacturing option in addition to the established processes. Every manufacturing process has its specific strengths and weaknesses. In the conventional manufacturing process by e.g. machining, these are known and are appropriately considered in the design and in the selection of the manufacturing process. In additive manufacturing processes, the designers still largely lack this wealth of experience. Like any manufacturing technology, additive manufacturing also needs certain framework conditions in which it achieves the best cost-benefit ratio. In the future, too, industrial 3D printing will only be a technically sensible and economical alternative to conventional manufacturing technologies for certain manufacturing tasks. AM offers advantages in particular for complex component geometries that are produced in small series.

Additive manufacturing is not an isolated production process that produces finished components in one step, i.e. the components produced by AM are not immediately ready for installation in another product or good. Rather, additive manufacturing is a single step in a manufacturing process chain from powder to product. For example, powder residues and support structures still have to be removed from the components, and threads and fits require conventional post-processing. For this, conventional manufacturing processes such as turning, milling or grinding are used in a complementary manner. The possible substitution of conventional manufacturing processes by AM is closely linked to the need for post-processing. Such a high resolution of AM processes that makes post-processing by other manufacturing processes obsolete, is not yet in sight.

Both 3D printing processes for the production of metallic components and components made of plastic are used industrially. Current challenges for the industry in relation to AM processes are multi-material processing, surface quality, process reliability, integration into existing production processes and, in general, knowledge building. In the industry, the additive manufacturing process "Selective Laser Melting" (SLM) is by far the most frequently used for the manufacture of metallic AM components.

Additive Manufacturing Fact Sheet

Industry Sectors

Industry:

- Medical technology (inexpensive production of individualized medical products, e.g. implants)
- Tool and mold making (manufacture of special tools)
- Aerospace (close-contour production of components made of expensive materials, weight savings through bionic design)
- Automobile (production of prototypes, rather little series production)
- Mechanical engineering (spare parts)

Research areas:

- New materials (powder development) and process parameters
- More efficient manufacturing processes (e.g. higher build rates)
- Improvement of product properties (e.g. surface quality)
- Reducing the need for post-processing

Export control relevant Applications

A specific military application area cannot be determined, as AM is a universal manufacturing process and workpieces can therefore be manufactured for a wide range of applications. Due to the wide variety of applications, it is consequently not a key process for the production of military or proliferation-relevant workpieces.

However, the advantages for industry associated with the use of AM processes can also be transferred to military applications. The use of AM processes in the context of military product development could lead to shorter development times, since prototypes can be realized and tested more quickly. In the area of spare parts production, too, faster availability of spare parts for military goods could be achieved. In addition, AM processes in relation to military aerospace could lead to advantages through the realization of lighter components.

In general, both for civil and military applications, the combination of conventional manufacturing processes together with AM, in particular by specialized market operators (e.g. AM-integrated production facilities) can lead to a qualitatively enhanced production process allowing to produce entirely new and/or enhanced products. The use of such AM-based products can naturally lead to advances and/or advantages in military applications.

Current Listings

A large number of AM-related listing items already exist:

- Technology indispensable for the development of sensitive components
- Technology indispensable for the manufacture of sensitive components
- Various materials, especially metal powder
- Equipment for the production of metal powders
- Specially designed AM systems for the production of directionally solidified components (especially engine blades)
- Components of AM systems, especially lasers
- Production machines for the post-processing of AM components, especially for turning, milling and grinding
- Measuring machines for quality assurance, especially coordinate measuring machines
- Sensitive components that were manufactured using AM.

Aerospace – Hypersonic Propulsion Technologies
Fact Sheet

TRL

Industry:
Missile prototyes (milit.),
e. g. Awangard (RUS),
X-51A (USA), DF-ZF (CHN)

Science:
Concept studies, commercial
Intercontinental connections

General Information

Hypersonic refers to supersonic speed above 5 times the speed of sound. The physical effects of re-entry (Mach 5 to Mach 25) of space vehicles (capsules, shuttles) or ICBMs are known. From Mach 5, the heat generated by the friction of the air flow is the determining fluidic effect.

Due to the high heat generation, only cooled structures or selected materials and / or thermal protective layers can be used here. Materials are known and researched from space applications.

The emerging military hypersonic missiles should also be manoeuvrable, which increases the technical requirements for such systems.

Engines for hypersonic:
- Rocket engines (known)
- Air-breathing engines (see technology fields), traditional turbojet engines cannot be used at these speeds because the air flow in the engine must be decelerated to subsonic (frictional heat), hence the development of other engine concepts.

Technology Fields

- **Engines**
  - Scramjet - ramjet engine with supersonic combustion.
  - Detonation engines - air-breathing propulsion system with detonative instead of continuous combustion
- **Heat-resistant materials, sensors**
- **Flight control**
- **Test, development and simulation facilities**

Aerospace – Hypersonic Propulsion Technologies
Fact Sheet

Industry Sectors

Currently no applications for hypersonic missiles.

Export control relevant Applications

Military:

- Hypersonic glide vehicles are brought into near-earth space by rockets and generally continue to fly without propulsion; there may be small propulsion systems for certain manoeuvres.
- Hypersonic cruise missiles are faster variants of their conventional counterparts that reach their target continuously propelled.
- Hypersonic missiles are difficult or even impossible to defend against with traditional systems: The combination of high speed, long range, manoeuvrability and low altitude makes them difficult to detect, allows large areas to be potentially threatened and reduces the reaction time for countermeasures.

Public security agencies:

- Currently no applications for hypersonic missiles.

Current Listings

9A011 - *Ramjet-/Scramjet*-Turbines

9B107 - Test systems for aerothermodynamics (flow studies at high temperatures)

Quantum Technology
Fact Sheet

TRL

Science & Industry: Basic and applied Science

General information

Quantum technology covers several areas in which quantum effects are exploited. These effects are in particular the superposition (quantum objects can have several superimposed statuses at the same time) and entanglement (two or more quantum objects always have the same status although there is no connection between them). The main subject areas are quantum computers, quantum sensors and quantum cryptography:

A **quantum computer** uses so-called qubits that can be in superposition. This means that operations are carried out greatly simultaneously which is advantageous for certain operations, e.g. searching in large unstructured databases, solving linear systems of equations or factoring large numbers. Hence, the potential of quantum computers will most likely be used for applications in optimization problems (including artificial intelligence) or material simulation (e.g. of drugs or raw materials). It will become the new generation of high-performance computer (with special algorithms). In the longer term, a powerful and scalable quantum computer endangers certain information security technologies. This applies in particular to asymmetrical encryption methods, the security of which is based on specific mathematical problems that with conventional computers are difficult to solve.

For the time being the most advanced technologies for constructing a quantum computer are ion traps and superconducting integrated circuits (Josephson qubits). For both to be realized it takes extremely low temperatures. Besides the complexity of the structure, the basic challenges which need to be overcome are scalability and error correction. In addition to the two technologies mentioned above, there are other technological approaches followed by different groups of researchers.

As regards **quantum cryptography**, current technology focuses on the so-called quantum-key-distribution (QKD). Thereby, the keys for encryption and decryption of a later communication via open networks are exchanged on a quantum basis. Contrary to traditional encryption methods, the entanglement makes any slide change during the QKD-process detectable. Thus, the communication partners will notice if the key exchange has been spied on. In addition, other quantum cryptography technologies are under research.

Quantum sensors take advantage of the fact that quantum effects are very sensitive to changes such as acceleration, rotation or electric or magnetic fields.

Quantum Technology
Fact Sheet

Industry sectors

Many governments and research organizations as well as large Tech companies are currently investing highly in the development of quantum technologies. It is thus, difficult to estimate when quantum technologies will be available for commercial use and which markets or fields of application will likely benefit from them.

- **Quantum computer:** Wherever a classical supercomputer fails today due to the complexity of the task, a quantum computer might offer a solution, e.g. for optimization tasks or simulations.
- **Quantum cryptography:** Is particularly relevant for the security of high-quality communication (military, politics, authorities) or particularly sensitive areas (banks, insurance companies, healthcare).
- **Quantum sensor:** These new types of sensors take advantage of the effect of quantum physics and have the potential improve certain sensing tasks through a combination of spatial resolution, sensitivity and robustness, e.g. potential to improve medical diagnostics by measuring tiny magnetic fields from the heart and brain.

Export control relevant applications

The above identified areas of potential relevance for industrial applications can also be transferred to safety-related applications.

Military:
- Weakening of information security of opponent (quantum computer)
- Securing of own information security (quantum cryptography)
- Powerful sensors, inter alia against stealth technology (quantum radar)

Public security agencies:
- Powerful computers for specific applications and operations
- Securing of information security
- powerful sensors with better spatial resolution, sensitivity and robustness for certain measuring tasks

Current listings

- **Quantum computer:** no specific listing position, however, 5A004a (Systems in order to circumvent, weaken or overcome information security) and 5A002a (Systems for information security with quantum safe or quantum resistant algorithms), Listing proposal for quantum computer in Wassenaar, category 4
- **Quantum cryptography:** 5A002c (Systems designed or modified to use or execute quantum cryptography)
- **Quantum sensors:** multiple general listing positions for sensors in category 6
- **Quantum technology** (in general): supporting technologies (Low temperature, lasers, semiconductors, manufacturing equipment) in categories 1, 3, 4 and 6

Semiconductor Technology
Fact Sheet

TRL

Industry:
Applied

Science:
Further Research

General Information

Semiconductor technology describes the sequence of various, mutually coordinated process steps for the production of electronic or opto-electronic components on the basis of semiconductor materials. Typical process steps are: coating, etching, doping, photolithography, metallizing. Depending on the material used, two very different types of semiconductor technology can be distinguished:

- Silicon technology: Based on the chemical element silicon. The aim is to reduce the structure widths constantly so that more transistors (functions) fit on 1 cm^3 substrate.
- Compound semiconductor technology: Based on the chemical combination of two (or more) elements, e.g. gallium and arsenic to gallium arsenide. The aim is to develop new combinations of materials in order to increase e.g. switching frequencies, sensitivities or temperature resistances.

Semiconductor technology also includes circuit design as well as chip design, i.e. the adaption of a function into a circuit plan and based on this plan the development of a chip layout.

Systems-on-a-Chip & Stacked memory on Chip

Systems-on-a-Chip (SoC) describes the partial or complete integration of electronic systems on a single chip (IC). The systems are often based on existing components. Usually SoCs specially designed for the planned area of application as regards hard- or software. Whilst the special hardware design offers faster response times, the special software design is more flexible in terms of functionality and updateability.

Stacked memory on chip is a technology for a three-dimensional architecture of memory units. Several storage layers are placed on top of one another and integrated in a chip.

The advantages of SoCs and Stacked Memory on Chip compared to classic solutions are inter alia cost efficiencies, reduced dimensions, shorter response times, lower energy consumption and improved reliability. Disadvantages are the complex design, the problematic internal heat dissipation and the increased susceptibility to errors in the manufacturing process of the ICs.

SEMICONDUCTOR TECHNOLOGY
FACT SHEET

TECHNOLOGICAL FIELDS

- **Silicon technology:** Production of mass components, which can be found in almost all areas of daily life, e.g. computers, cell phones, air conditioning systems, weapon systems, TV, industrial controllers, military equipment, etc. They are all based on integrated circuits (microprocessors, memory modules, logic circuits, etc.), transistors, diodes or CCD chips (for cameras). See also "micromechanics".
- **Compound semiconductor technology:** Production of mainly opto-electronic sensors, laser diodes, light emitting diodes or high frequency transistors in large numbers. Not comparable with mass production of silicon components, except for the LED production.
- **Micromechanics:** Also called MEMS. Manufacturing of miniaturized mechanical parts using the mechanical properties of silicon. For example pressure membranes, bending beams, micro-adjustment devices.

INDUSTRY SECTORS

Semiconductor industry supplies components for basically all industrial sectors.

Applications (Selection):

- **Information technology:** Processors (CPU) and graphic processors (GPU) on IC, Smartphones; PC semiconductor hard drives (SSD); tablets and laptops for a wide range of functions with more space for battery pack and longer battery life; Encryption; Sensor data processing
- **Controller and Automation:** Washing machines; Industrial machinery; medical devices; Automotive technology (including autonomous driving); Avionics
- **Communication technology:** Data terminals (e.g. radios); Encryption; Mobile communication; Satellite communication
- **Sensors:** Cameras, thermal imaging devices, pressure sensors, acceleration sensors
- **Laser:** Laser diodes in many applications (Material processing, analytics, measurement technology)
- **Lighting:** LEDs for intelligent street lighting, LED-lamps

EXPORT CONTROL RELEVANT APPLICATIONS

Military:
Electronic components, which through optimized and further developed semiconductor technology are capable of high performance combined with small dimensions and at the same time high robustness, are also of interest to a lot of military applications, for example:

- Basically all weapon and combat support systems
- Optical reconnaissance (infrared, multispectral, visible wavelength range, ultraviolet)
- Secure communication (encryption)
- Electronic warfare (ECCM)
- Avionic (Avionics Cockpit Displays)

Public security agencies:

- Search and Rescue, tracing, disaster control etc.

CURRENT LISTINGS

The EU dual use regulation covers in 3B and 3C general manufacturing equipment and materials primarily for compound semiconductor technology. As regards silicon technology, only photolithography and cluster tools are listed (3B001f and 3B001e) as well as lithography masks for listed chips.