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Applications of Nanotechnology in Space Developments and Systems

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- Introduction
- Overview on nanotechnology research
- Nanotechnology applications for space
- Contributions to future space technology objectives
- Conclusions

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„Technology and knowledge transfer in emerging technological fields - Interface for academia, politics and industry"

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„One of the main promoters of nanotechnology in Germany since 1990 - technology forecasting and assessment"

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ANTARES Study - Applications of Nanotechnology in Space Developments and Systems

- **Objective**

⇒ Identify and assess potential nano-technology applications for space

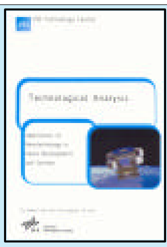
⇒ Derive recommendations and further R&D demand

- **Client**

⇒ German Aerospace Center

- **Duration**

⇒ 15 Months until end of 2002



„Application of Nanotechnology in Space Developments and Systems", VDI Technology Center, Future Technologies No. 43 EN, April 2003, ISSN 1436-5928)

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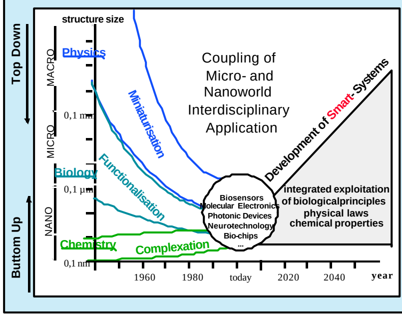
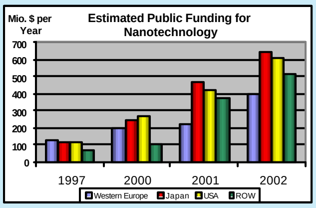
What is Nanotechnology?



Controlled production, analysis and use of structures

- smaller than 100 nm at least in one geometric dimension
- with new physical, chemical or biological properties which do not occur above these critical dimensions (e. g. quantum effects)

Development of Public Nanotechnology Funding



- Japan and USA leading with regard to public nanotechnology funding
- ROW countries are catching up (e.g. Taiwan, Korea)

Source: Roco 2002

US: National Nanotechnology Initiative since 2000 „national task“
EU: Nanotechnology Funding in 5th and 6th Frame Work Programme
+ National Nano Funding Programmes (D, CH, F, UK etc.)

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Nanotechnology Activities in Space

United States

- NASA: 46 Mio. $ Nanotechnology Budget in 2002
- Many cooperations with companies and other agencies (e.g. Small Business Innovation Programme)
- Focus on basic research and short to midterm space applications

Europe

- Nanotechnology as subordinated topic of microsystem technology
- Only few nanotechnology projects with focus on space applications
- Some connection points in the framework of the AURORA-Programme and Advanced Technology Studies of ESA

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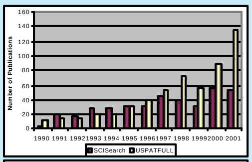
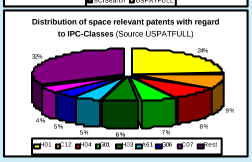
Analysis of Space-Relevant Nanotech Publications



Significant increase of space-relevant nanotechnology publications in scientific and patent literature



H 01 BASIC ELECTRIC ELEMENTS
C 12 BIOCHEMISTRY
H 04 ELECTRIC COMMUNICATION TECHNIQUE
G 01 MEASURING; TESTING
H 03 BASIC ELECTRONIC CIRCUITRY
A 61 MEDICAL OR VETERINARY SCIENCE: HYGIENE
G 06 COMPUTING; CALCULATING; COUNTING
C 07 ORGANIC CHEMISTRY

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Potential Contributions of Nanotechnology to Future Space Technology Objectives

Cost Reduction
- Decreased mass, volume and energy consumption of space systems
- Improved On-Board Autonomy
- Increased operating life of space systems

Improved Capabilities
- Improved communication performance
- Instruments and sensor breakthroughs
- Innovative components and materials
- Intelligent space systems operations

Lowering of Mission Risks
- Improved error recognition and correction
- Increased fault tolerance
- Distribution of mission task to a multiplicity of small systems

New Space System Concepts
- constellations of miniaturized satellites
- Gossamer-Spacecrafts
- Robotic inspection probes
- Visionary space elevator

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Nanotechnology Disciplines vs. Space Technology Requirements

Nano-Discipline	Topics
Functional ultra-thin films	• Biomolecular layers • Mechanical and protective layers • Ultrathin layers for optics and photonics • Nanoactuators and sensors ....
Lateral nanostructures	• Magnetoelectronics • Sub-100 nm CMOS • Self-Assembly, Lithography ......
Nano-Analytics	• Scanning tunneling/ force microscopy • Near-field optical microscopy • Electron microscopy ......
Nanochemistry/ -materials	• Sensors & catalysis • Nanoparticles • Design of nanomaterials ....
Nano-Optoelectronics	• Quantum dot laser • VCSEL • Photonic crystals .....
Ultra-precise surface treatment	• Ionbeam- and plasma methods • Ultraprecise 3D-structuring • Nanopositioning systems ......

Potential contribution to space objectives

Space Application fields

- **Earth Observation**
- **Telecommunication**
- **Navigation and Positioning**
- **Science and Exploration**
- **Manned Space Flight and Microgravity**
- **Long Term Applications**
- **Generic Technologies**
- **Space Transportation**

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Potential Applications of nanotechnology in space

Nano-Competence Centers (CC) ® / Space technologies	Nanochem., Nanomat.	Nanolayers	NanOp	Lateral Nanostruct	Ultraprecise Surfaces	Nano-analytics
Earth Observation						
Microwave equipment and antenna technologies						
Components for Limb-Sounder and SAR (Amplifier, diodes, etc.)		√		√		
Optics/Optoelectronics						
Extremely high resolution optics, lightweight Optics, high integrated CCD	√	√		√	√	
High temperature IR sensors (QD), Microbolometer		√	√	√		
LIDAR-technologies						
Diode pump laser for solid state laser (QD, QW-lasers)			√			
Telecommunications						
On-Board equipment technologies						
Components for data communication in the EHF-Band (SSPA, HEMT, HBT, etc.)	√	√		√		
Components for optical data communication, Intra- and Intersatellite links		√	√			
Antenna technologies (e.g. large, lightweight and unfoldable antennas)	√	√			√	

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Navigation und Positioning						
On-Board equipment technologies						
Electronic components (Amplifier, transistors e. g. SSPA)		√		√		
Science and Exploration						
In-situ instrument technologies						
Miniaturized instruments for geochemical analyses (e. g. AFM devices)						√
Aerogel for particle detection	√					
X-ray technologies						
Mirrors for X-ray astronomy		√			√	
Laser technologies						
Diode pump laser for ultrastable solid-state lasers (LISA-Mission)			√			
Optical technologies						
Lightweight IR-Optics, high integrated CCD (GAIA Mission)	√	√		√		

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Manned spaceflight and microgravity						
Life support technologies						
Gas sensors, biochemical sensors, electronic nose	√			√		
Oxygen generation	√					
Waste water and exhaust air treatment	√					
Heat exchanger	√					
Biomedical monitoring of astronauts	√					√
Thermal protection technologies						
Improved thermal protection systems, hot structures and re-entry technologies for earth and mars atmosphere	√	√				
Robotics and automation						
Miniaturized sensors (mechanical, chemical, thermal, radiation etc.)	√	√		√		
Miniaturized and integrated electronics	√	√		√		

Potential Applications of nanotechnology in space

Space technologies / Nano-Competence Centers (CC) ®	Nanochem., Nanomat.	Nanolayers	NanOp	Lateral Na-nostructure	Ultraprecise Surfaces	Nano-analytics
Generic technologies						
Structure technologies						
High strength lightweight materials for space structures (MMC, CNT, plastics etc.)	√					
Energy generation and storage						
High efficient solar cells (Multi junction III/V-semiconductor, QD, dye, polymer etc.)	√	√		√		
High efficient fuel cells (SOFC, PEM), hydrogen storage, batteries (Li-Ion, NiH_2), supercap acitors	√					
Thermal Control and Protection						
High temperature technologies for operations up to 2000 °C (ceramic composites)	√	√				
Thermal control layers (e.g. DLC)		√				
On-Board data processing and data comm unication						
Radiation hard microelectronics (e.g. MRAM, SOI, ASICs)		√		√		
Energy saving high performance data processing	√			√		
Mass storage	√	√		√		

Potential Applications of nanotechnology in space

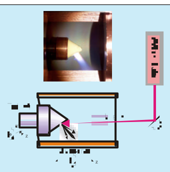
Space technologies / Nano-Competence Centers (CC) ®	Nanochem., Nanomat.	Nanolayers	NanOp	Lateral Na-nostructure	Ultraprecise Surfaces	Nano-analytics
Space transportation						
Liquid propulsion systems						
Gas sensors for engine monitoring	√	√				
Improved turbopumps and lines	√					
Solid propulsion systems						
Materials for housings and nozzles (e. g. reinforced polymers)	√					
Improved propellants, non-chlorinated, (e. g. aluminum nanopowders)	√					
Materials, thermal protection						
Hot structures and thermal protection for re-entry and rocket propulsion (ceramic fiber composites, gradient layers etc.)	√	√				

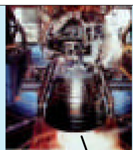
Nanostructured heat-insulating layers for rocket engines by means of Pulsed Laser Deposition

Advantages

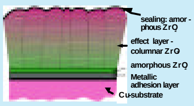
- Nanostructured gradient layers provide better heat and corrosion protection for combustion chambers in rocket engines
- can be matched to the load profile

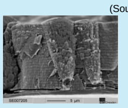
➽ **higher performance, potential for reusable engines**





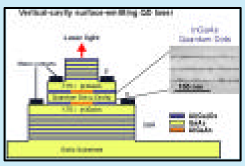
ARIIANE 5 Vulcain Engine (Source: ArianeSpace)

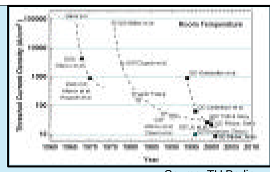




above: principle of interior wall coating with PLD process; below: schematic layer structure and REM image of a heat-insulating layer manufactured with PLD, Source: FhG-IWS, Dresden

Quantum Dot Lasers for Applications in Optical Data Communication or Scientific Missions



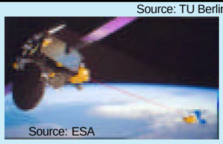


Source: TU Berlin

Advantages of QD Lasers

- Lower energy consumption
- High modulation range
- Improved temperature stability and radiation hardness

➽ **application potential as pump laser for laser applications in space**



Source: ESA

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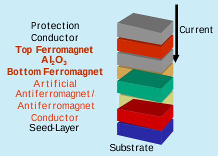
Magnetoelectronics for sensor and data processing applications in space



TMR Junction (Source: Uni Bielefeld)


Simplified structure of a MRAM made of TMR-elements

Potential of magnetoelectronics for space application
- energy saving and radiation hard data memory
- miniaturized position, acceleration or rotation sensors
- potential for field programmable logic

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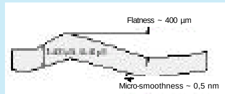
Advanced x-ray optics


Optical Design of the XMM Mirror Moduls (Source: ESA)



Glass Microsheet (e.g. Schott D-263) as candidate for thin-foil -ray optics (Source: Center for Space Research MIT)

Nanotechnology applications for x-ray optics
- Ultraprecise surface finishing of x-ray optics (conventional Wolter optics)
- New concepts for thin-foil x-ray optics (significant increase of collecting area-mass-ratio)
- Further improvements in shaping, coating and assembling foils with nanoscale precision is necessary

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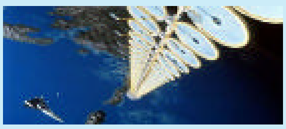
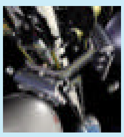
Nanomaterials for Space Structures


Visionary NASA Sun Tower Concept for solar energy production in space (Source: NASA)


Vision of a space elevator based on ultra-strong CNT materials (Source: www.space.com)

Potential of nanomaterials for space structures
- Significant increase of strength-weight-ratio seems possible by nanoscale material design (e.g. CNT)
- Broad range of material properties and application ranges a by different material classes and configurations (Metals, ceramics, polymers, composites ...)
- Potential for visionary space systems (Space elevator, Sun Power Satellites, Gossamer-Spacecrafts ..)

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Criteria for evaluating the space relevance of nanotechnological components

- State of development of the technology
- Economic potential in terrestrial markets
- Contribution to space technology objectives
- Economical benefit for the space sector
- Potential application obstacles in space

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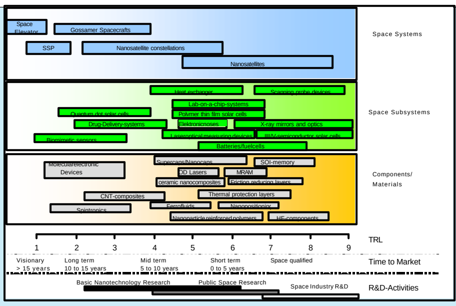
State of Development of Nanotechnology



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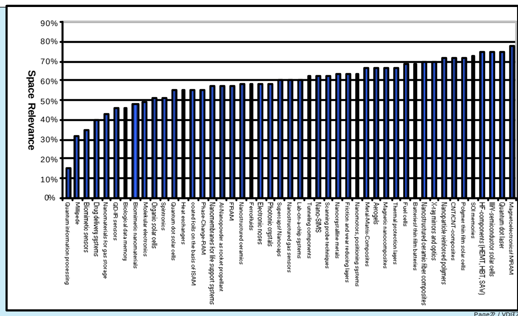
Evaluation of space relevance of selected nanotechnoogical components



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Conclusions

Nanotechnology potential for space applications:

- **Short to Midterm:** Improved components/ subsystems for space systems
- **Long term:** Enable innovative and revolutionary space systems

Recommendations:

- Monitoring of the technology field
- Intensification of communication between nanotech and space communities
- Strategic integration of nanotechnology into long-term space programs
- Realization of measures for space utilization of nanotechnological components