

INFORMATION SOCIETIES TECHNOLOGY
(IST)
PRIORITY



”New Manufacturing technologies for miniaturised ICT”

An IST Workshop contributing to the next Framework Programme (FP7)

Brussels, 22 February, 2005

REPORT

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SCOPE

The Information Society Directorate-General of the European Commission called leading stakeholders in Europe to a workshop on 22 February 2005, in Brussels, for preparing the future priorities in the area of “*New manufacturing technologies for miniaturised ICT*” as an input to the next Framework Programme for Research (FP7). These activities are undertaken in view of the ongoing discussions within MANUFUTURE (www.manufuture.org) on one hand and the ongoing public consultations for FP7 on the other. The workshop has been jointly organised with IMS-NoE (www.ims-noe.org).

The emphasis was on discussions to improve the European Industry competitiveness by improving the manufacturing process of miniaturised ICT devices, micro-systems and their integration in smart integrated objects and systems. The main objective of the workshop was to identify potential areas of need for research funding actions in the upcoming 7th framework program. It does not address the use of ICT to optimise the production processes but may use and benefit from general developments in this direction.

Manufacturing Technologies for Miniaturized ICT have a broad scope ranging from micro- and nano-electronics and micro-nanosystems to larger systems using micro-nanotechnology as main driver for their improved characteristics. It goes beyond Silicon (which will remain however an important foundation) to include novel components at the micro- and nano-scale. It also expands on the system-on-chip theme by moving to a system-in-package, which will allow to combine devices and components from very dissimilar materials and, through the use of inexpensive assembly techniques, opens opportunities also for small and medium-sized companies. It covers smart integrated objects in miniaturised form e.g. Rf tags and the integration into a macro-system. Fully automated high volume production of commodity goods is targeted as well as the lower volume high value added customised production targeting the high end markets which is populated by many innovative SMEs and start-ups.

In contrast to developing the new technologies upon which it builds, manufacturing research deals with the development of industrial processes, equipments and methods and the scale-up of fabrication towards commercially viable volumes. Because of the massive capital expenditure necessary in microelectronic and nano-electronic fabrication, ways to improve the efficiency of production there were another topic of the workshop.

ECONOMIC DRIVERS

Manufacturing is considered critical to economic growth and a major source of wealth for Europe. Manufacturing of High-Tech and Medium High-Tech products in Europe¹ accounted for 12 million jobs² in 2001 (7.4% of total employment in EU-15 and roughly 38.5% of all jobs in Manufacturing).

In 2001, Europe’s¹ the High-Tech sector alone accounted for roughly 20%² of EU-15’s total external trade, amounting to 195.5² thousand million EUR, mainly in the shape of Electronic (30.9%) and Aerospace (25%) products. But external trade is only one side of the story, Europe’s³ High-Tech sector also generated some 466.3⁴ thousand million EUR in Intra-EU

¹ EU-15

² “Statistics on Science and Technology in Europe part 2”, Eurostat 2003 ISBN 92-894-6823-8

³ EU-15

⁴ Statistics on Science and Technology in Europe part 2”, Eurostat 2003 ISBN 92-894-6823-8

flows in 2001, a considerable trade volume.

Moreover, Europe's¹ High-Tech sector generates, not surprisingly, the bulk of patent applications in Europe. Regions that feature high incidence of High-Tech Manufacturing operations are invariably top in terms of no. of patent applications submitted to the EPO⁵. Also, 85.7%² of all patent applications in 2001 fall under either Computer equipment, Communication Technology, Semiconductor or Aviation products, product areas that usually feature a high degree of integration and reliance on miniaturised devices.

The impact that ICT can have on productivity, efficiency and new product functionality is enormous! More efforts should be devoted to the rapid transfer and implementation of the new ICT technologies into manufacturable products. As more ICT products become customised, the time to market and first time right issues are becoming predominant, customised flexible production is becoming a key aspect to support this innovation process. That trend is another opportunity for Europe to keep manufacturing close to its customers in Europe as compared to the extreme cost pressure on monolithically integrated commodity products. In this context a research strategy should be defined to bring into manufacturing all the know-how, skills and knowledge generated in Europe in the nanoelectronics and integrated micro-nanosystems areas.

Customisation and mass-manufacturing of core miniaturised ICT devices and micro-systems to produce high added value products are gaining an increasing role in the economy. The customised products are more common in the micro-nanosystems where the technology depends strongly on the system requirements, whereas the mass-manufacturing products for commodities are more common in the microelectronics area.

Europe has a strong position in the areas of metrology and analysis, in specific types of manufacturing equipment and processes and in most of the micro-nanosystems technologies; however it has not such strong position in bringing the device technologies into manufacturing of meaningful volumes. For example in investment in "standard" microelectronics fabrication, Europe lags significantly behind the leading area, the Far East (62% of overall investments in 2002), the Americas (20%), and Japan (10%): only 8% of all capital expenditures in the area of microelectronics manufacturing in 2002 were spent in Europe. There is a need to bring part of these investments in manufacturing back to Europe, capitalizing on a trend towards more customised products and to maintain and strengthen manufacturing competencies to integrate – monolithically and in package - components and devices in innovative miniaturised smart integrated systems.

PRESENTATIONS AND DISCUSSIONS

Several individuals presented their company or institution's views during the workshop (see list of attendees). The workshop was chaired by Andrew Richardson (University of Lancaster) and Hermann Schumacher (University of Ulm). Several trends were highlighted.

1. There was an overall consensus that many future miniaturized systems will still be dominated by silicon; however functions need to be added on top of silicon, such as sensors and actuators. These new functions can be provided in some cases monolithically, using above-IC processes, or in a hybrid form using system-in-package concepts. Micro-electro-mechanical structures (MEMS) integrated on top of silicon will play a larger role in the future.

⁵ European Patent Office

2. As dimensions shrink, two currently separated integration strategies will merge: the standard "top-down strategy using lithography – and increasingly self-alignment - to define the lateral arrangement of structures, and the "bottom-up" of self-assembly. Significant effort will be required to move the latter from laboratory experiments onto the manufacturing floor.
3. There is still a strong need to improve the tools necessary for microelectronic manufacturing in the current sense. Here, the desire was to make tools smarter, and to *gather* more real-time data through in-situ monitoring with direct feed-back loops and with feedback into the fab management system and to develop new strategies to *handle* the exploding volume of data produced throughout the manufacturing process.
4. Nanotechnology currently suffers from a lack of standardization, be it in technological processes or design approaches. Learning from the strong growth of ASICs in the seventies and eighties, more fab-independent design tools, modular approaches, standard interfaces and standard cells would allow nano-technological devices to gain a more rapid market acceptance (the same can be said for MEMS and Microsystems).
5. New devices for different applications using different materials or a mix of silicon with different materials are emerging. These will need very new and different manufacturing equipment, processes and approaches e.g. a reel-to-reel manufacturing for very low-cost electronic and optoelectronic applications, printing devices on different substrates, etc... These manufacturing techniques could be applied to a wide variety of substrates, from paper through cardboard to textiles. The use of these new technologies in innovative applications presents a new opportunity to develop and maintain their manufacturing in Europe. E.g. some reel-to-reel printed electronic components are attractive in health care and present a high volume potential as they can be easily disposable. (Printing industry is well developed in Europe and is looking for innovation.)
6. The new microsystems with high added value present another opportunity to increase manufacturing jobs in Europe, especially if they are in more customised, relatively low-volume, high-price market segments which require a high degree of manufacturing flexibility and significant skills. Microsystems in health care are again an excellent example, safety and security systems are another.
7. Microsystems opportunities are often exploited by small and medium sized companies, which do not necessarily have all production capabilities in house, provided that the underlying processes can be highly modularized, so that production can take place in a distributed, multi-vendor environment.
8. The large importance of power subsystems in advanced microsystems was also highlighted. Manufacturing in this area would also benefit from a higher degree of standardization of interfaces, and a higher degree of integration. However, the latter will need research to better understand the thermal management of microsystems.

OBJECTIVE SETTING

In this very complex field there are different technologies in a different state of maturity and with different market requirements to be covered. Different objectives and strategies were defined based on the maturity and business model.

- **Micro-/nano-electronic devices (produced in a single fab)** where the aim is at “monolithic” devices. The device itself is packaged to become a component with the package showing not much active functionality. Two directions can be distinguished:

1) Megafabs, mostly located outside Europe, for very high volume commodity products that usually are being fabricated predominantly in the same technology. However, their complexity can vary very significantly. The trend towards smaller dimensions and to incorporate always more functionality brings in the manufacturing line the need to address under the same roof more different materials and different type of processes with metrology, manufacturing efficiency, equipment utilisation and cost considered very important aspects.

2) Fabs that produce a large number of customised components in one line in which case the trend is towards more diversification including also the combination of different technologies under one roof. The trend towards System-on-a-Chip requires for instance the integration of different CMOS and non-CMOS technologies in the same IC process flow. The re-use of processes and equipment and the “flexibility versus the cost” target are important for this type of factories. In silicon based production facilities, compatibility with and following the trend towards smaller dimensions in (often older generations of) megafabs is considered another requirement.

- **Heterogeneous components (produced using different fab-lines)** where two or more facilities or fab lines are needed to produce the component. These lines are often in completely different fabs as in many cases manufacturing processes are not compatible to be manufactured under one roof, in one line. They are distinct from monolithic micro-/nano-electronic devices in that they typically combine dissimilar materials e.g. silicon and polymer, or need different competencies e.g. microstructuring for microfluidics combined with traditional electronics. Heterogeneous as well as monolithic integration (on top of IC integration) can be foreseen depending on the purpose and on the production volumes. Packaging is often playing a more active role and always adds functionality. System-in-a-package is one of the options. Wafer level packaging and hybrid assembly techniques are often used to facilitate transfer between fablines. System requirements have to take also the integration and interfacing with the overall system into account. In case of microsystems also the interface with the application requirements and interfacing with the environment is important. The modularity of processes, techniques and interfaces between the different contributing fab-lines / companies are important factors to take into consideration. Today often driven by customised and smaller volume requirements; these fabs aim at a flexible implementation of manufacturing flows, however taking also cost aspects into account. Many of developments related to heterogeneous components are just entering the production stage and will require a fast transfer from a ‘prototyping stage’ of equipment and practices into a more industrial stage. Multi-disciplinarity, being able to master in a controlled production manner 2-dimensional and 3-dimensional structures, active use of new material properties; mixing electrical and non-electrical properties (even biological) in a controlled reproducible manner present a main challenge and a major objective for the manufacturing research.
- **Integrated systems (smart systems)** where the fabs are bringing devices and components from the two previous objectives together to generate (smart) miniaturised integrated systems in very small form factors e.g. smart pill. These are the typical assembly plants to generate smart miniaturised products or, on the other side of the spectrum, to generate macro products (polymer) using new functionality given by micro and nanotechnology (polymer devices, smart lab cards, etc...). A full range of different assembly techniques is used. Sometimes also revolutionary disruptive manufacturing technologies are penetrating this field to generate fully integrated miniaturised systems, e.g. Roll-to-Roll printing of smart functional devices. Some of these assemblies have full self contained functionality and may be of high volume / low cost e.g. disposables, ID-tags, ... However, as more often the case, these are customised smart objects, or smart subassemblies, to be integrated

in or interfacing with larger systems or a network. Depending on volume and maturity, they ask for a more flexible, customised or for a more standard, rigid approach; for a more handcrafted or a more controlled/automated approach. These integrated systems have also often to comply to different conditions related to their field of application (e.g. implantable systems, high reliability, high temperature systems ...) which puts specific conditions on the design / production / testing and manufacturing environment to produce these. Often we know how to produce efficiently the smaller dimension but how to efficiently, reproducibly and reliably mount together the integrated miniaturised systems is still an after thought ('mesoscopic gap'). No doubt that the Intellectual Property issues play a major role.

Each one of the cases above has different requirements for manufacturing research and also a set of "common" issues or priority areas. A matrix has been generated which interrelates them as shown in Annex 1.

In each of the cases above very new disruptive approaches for design and processing may emerge in the time frame of FP 7, e.g. 'bottom-up' self-assembly processes in nano-electronics. This will need close follow-up and manufacturing / industrialisation issues should be addressed as soon as possible when such developments arise. Addressing manufacturing research in combination and in parallel with materials, process and technology research is becoming essential to allow a fast transfer of research results into production.

It is also essential to address the whole "manufacturing" chain to produce a 'product' and take manufacturability, reliability, environmental, yield and test issues into account already at the design stage. Also the whole lifespan of the product need to be taken into account in view of increased emphasis on 'sustainable' development. The whole 'foodchain' to produce efficiently devices, components and integrated smart systems has to be looked at. Building successful partnerships between European customers and manufacturers or groups of manufacturers will allow to develop and to manufacture innovative and more performing European products more efficiently.

Networking between research communities, manufacturers and their suppliers of manufacturing or support equipment, materials, the infrastructure, automation, etc... will allow directly exploiting and further developing European strengths in specific topics. Pooling resources and competences on a pan-European scale and organising technology/equipment assessment, transfer of innovation and best practices will also help to increase critical mass and to export some of these specific European strengths and European research results globally. In the case of s-o-a semiconductor manufacturing given the complexity of the technology, it is no longer possible to be excellent in Europe alone in all the research aspects related to all steps in the manufacturing flow; however exploiting the existing European excellence in specific strategic topics should allow to keep a good overall European presence in this field.

In new emerging fields such as mixed technology heterogeneous components (e.g. combining nano-technology and/or nano-electronics and bio-technology) or Smart Integrated Systems using integration of different materials/technologies (polymer and silicon; micro-fluidics) manufacturing research need also to be linked with innovation stimulation and with policy initiatives to stimulate and facilitate wider and faster commercialisation. Shared infrastructure initiatives to execute in a cooperative manner RTD in manufacturing, engineering, prototyping and small volume and incubator areas for SMEs with support services for test, design are necessary to transfer results faster from research into pre-production. Innovation poles, located in a number of regions of Europe, pooling competencies of research institutes, of manufacturers, their suppliers and the designers of innovative products together around a few specific emerging topics (e.g. bio-microsystems, smart textile ...) are highly desirable. Financial incentives for facilitating starting-up manufacturing businesses and for expanding or

changing of existing manufacturing are necessary to grow from a pre-industrial stage into volume production. It must be recognised that the financial requirements and risks related with manufacturing projects and the manufacturing of products are often too high for one SME alone. Moreover the risk after successful starting up pre-manufacturing to be taken over by mass manufacturing sites outside Europe is high. Policy initiatives to lower the financial burden and risk for SME in an initial stage and to support protection of IPR are also required.

In general Europe is facing a lack of engineers. In particular engineers being able to cope with the multi-disciplinarity involved in this field and being able to cope with the increasing complexity of the manufacturing processes to produce miniaturised ICT are mostly missing. Training and education initiatives are necessary and initiatives to encourage younger people to enter into manufacturing engineering.

RESEARCH PRIORITY AREAS

All these objectives present common priority themes but different main requirements based on the technology development, manufacturing maturity and market needs.

- **Production Management:** an increase in efficiency and flexibility is common to all three functional areas, however with different emphasis and priority.

In the already mature fabrication of microelectronic devices, the staggering capital expenditure necessary to open a state-of-the-art production facility for high volume production forces to improved utilization of the very expensive tools. This shall be achieved by a higher degree of automation, improved in-situ monitoring, and near-real-time communication of process data at an estimated data acquisition rate of 10^8 s^{-1} in the foreseeable future. The latter will require breakthroughs also in data mining and decision support systems. Other fabs are offering relatively large numbers of more customised components through to systems-on-chip, manufactured in smaller volumes and will require higher flexibility at a reasonable cost and focus on re-use of their equipment.

In heterogeneous components, manufacturing techniques are much less mature - many techniques will have to be moved from the laboratory to the factory floor first. Flexible manufacturing flows will be needed here especially, as these areas are believed to first target low-volume/high-unit-price markets. Above-IC, hybrid integration, and different packaging techniques are used. Standard interfaces and modularity between equipments and processes will require a more complex and more flexible manufacturing flow. A customer oriented or customer specified production planning and management may be required.

Innovative multi-component assemblies and smart integrated objects, integration into different materials, e.g. plastic, textiles, will open new opportunities for Europe. Small and medium sized enterprises are often producing only parts of the product and subcontract other parts of the process. Provided that a suitable modularization of process flows with sufficient standardization can develop and lead to a possible multi-vendor fabrication flow, many more opportunities for new production flows and new products will become available. The IPR issue have to be carefully considered to facilitate multi-vendor cooperation schemes.

- **Design for manufacturing:** The increase of complexity in all functionality areas leads to challenges in manufacturing, reliability, testing, which have to be addressed already at the design stage. Suitable design platforms exist for microelectronic devices while DfM (design for manufacturing) aspects are only starting to be integrated in such tools. Such platforms still have to be developed for

heterogeneous components and integrated systems. In the latter case, multi-domain design platforms are necessary which also account for effects of package and the environment and take into account the necessity to manufacture in different lines. Modularity in design flows and clean interfaces between different design systems need to be developed.

Due to the heterogeneity at the component and system level, self-test strategies are particularly promising.

Following success of the ASIC strategy, modularisation of component blocks of heterogeneous microsystems has to be pursued. Furthermore, parameterisation of the standardized modules, their characterization and parameter extraction techniques have to be developed.

The development of the design tools and techniques has also to be directed into facilitation of introduction of innovative concepts and new devices, thus contributing to shortening of the distance between research lab and commercial fabrication. This issue is of utmost importance for Europe.

- **Metrology and analysis:** For micro- and nanoelectronic devices, the overriding objective is process control. Suitable tools need to be available for reduced geometries down to the atomic scale. In-situ characterization techniques are necessary to enable near-real-time manufacturing control. At the nano-scale, new failure mechanisms will occur whose physical origins need to be explored before suitable metrology tools can be developed. The next step has to be the standardization of such measurement techniques - for example, there is no generally accepted way to characterize carbon nanotubes. Likewise, fundamentally important CD measurement at nanometer level suffers from lack of precise linewidth standards.

The characterization of novel materials is a common request at both the device and the component level. For heterogeneous components and integrated systems, an added problem is that many non-electrical properties need to be assessed, e.g. in fluidic systems, and that the structures are strongly three-dimensional. The heterogeneous nature will lead to new failure modes, which again need to be explored before the development of tools can begin. Existing measurement tools in the lab need to be brought to the manufacturing floor, where early testing (at wafer level) with high throughput is very important.

Self-contained integrated systems may operate in environments putting extreme demands on reliability or for specific conditions (e.g. health care!). This makes system verification under different conditions and reliability assessment a prime objective.

- **Equipment and manufacturing processes:** The development of new manufacturing equipment and processes for micro/nano-electronic devices is characterized by a further reduction in scale, down to the atomic layer, the increased use of the third dimension, and the introduction of novel materials. Developments are mostly done at a global scale oriented towards a global market. Apart from the need for higher automation of fabrication tools, manufacturing of micro- and nanodevices faces the challenge of having to provide interfaces to the molecular and atomic scale. New nano-technologies and device concepts are also emerging which will need totally different equipment and production concepts.

Fabs aiming at flexible multi-device production have the challenge to follow the same trend but with more modularity in their equipments and manufacturing

processes. These flexible fabs aiming at monolithically integrated micro/nano-electronic devices will need to re-use the existing equipment and sometimes the integration of new specific equipments (e.g. MEMS) in their production lines. Wafer-level packaging is another important issue, as some of the novel devices will need hermetic protection at an early production scale.

Many equipments and processes for heterogeneous components are available at prototyping level and need to be transferred into production equipments. A more modular and standard approach is suggested between the different comparable solutions available. The use of many different materials offers an opportunity for new production equipment and manufacturing process developments.

Heterogeneous components (and integrated systems) will also need new assembly and packaging solutions. As already mentioned above, the third dimension will be increasingly used, leading to the development of suitable stacking technologies. On the micro-scale, tools for micro-positioning and -handling are also needed, as well as suitable processes and equipments for precision assembly. At the nano-scale, self-assembly and stochastic assembly techniques are used and will need a totally different manufacturing / industrial support.

For the assembly of highly integrated systems, it was noted that we face a "mesoscopic gap": we know how to fabricate devices with micrometer dimensions quite well, even down to 100 nm or slightly below, but techniques for larger dimensions, from 10 μm to 100 μm , are much less developed, as well as the integration of small dimensions in larger areas. Here again prototype equipment and pre-industrial manufacturing techniques need to be transferred into a production environment. Manufacturing requirements/objectives may differ very much dependent on application and volume. A certain level of automation is required depending on volume. Production of for instance 'implantable' smart integrated systems in contact with the body require a different ('sterile') environment compared to for instance production of Rf-tags or the production of devices that need a high reliability. Despite many products are still low volume and are produced in a 'customised', prototyping manner, some however are using new techniques. New production techniques need different equipments e.g. Roll-to-Roll manufacturing of plastic electronics, sheet-to-sheet fabrication, ink jet printing of devices on large areas, integrated production equipments for lab on a card processing and for RFID-cards and tags, etc... All these target volume production, have special needs and capitalise on major European strengths as in automation, in the printing industry (ink) and so on.

- **Commercialization and infrastructure:** A general remark was that R&D funding needs to be extended to include an industrialization phase, as otherwise there is a gap between scientific demonstration of feasibility in the lab and practical use on the manufacturing floor - this is particularly a problem for small and medium-sized enterprises. Shared infrastructures, common services and incubator spaces were suggested. Due to the larger capital expenditures, microelectronic manufacturing tends to delay the uptake of new tools and processes and to concentrate on optimal use and re-use of the installed production base. Equipment assessment and exchange of best practices may provide early confidence on the capabilities and manufacturing performance of specific equipments to introduce these earlier in the lines.

Technology assessment is another overall objective in heterogeneous components. Unlike the current situation in microelectronics, where a well-established roadmap has been governing development for many years, the new manufacturing

technologies targeted here are being presented with a puzzling spectrum of possibilities. An early assessment (including simulation) of these options with an emphasis on projected manufacturability is therefore needed.

For the manufacturing of micro-/nano-devices, new paradigms using distributed facilities may lead to a reduction in the huge investment needed to establish semiconductor manufacturing plants. Feasibility studies of such fabrication flows already started and need to be expanded. Issues of study are e.g. quality tracking or contamination control. This is also important for heterogeneous components and for integrated systems. The need for distributed facilities and for different companies to offer joint solutions, to enable innovation in different products will require investigation into new business models. Legal issues such as responsibility sharing and IPR have to be carefully studied to allow for seamless joining of vendors in a joint manufacturing flow. Specific attention will need also to be given to the IPR situation in particular for safeguarding the role of SME in Europe in this innovation process. Due to the nascent state of heterogeneous component manufacturing (equally true for most miniaturised integrated systems), incubator structures are called for which enable the development of modular processes and provide business opportunities for SMEs without the need for large up-front capital expenditures.

- **Support measures:** Here, an emphasis on standardization in all three functional areas is important. It applies to process control and monitoring, to standardisation in and between equipments, to standard interfaces between modular processing blocks in heterogeneous components, to standards in metrology, design platform as well as to interfaces between components, subsystems in integrated systems.

Another common issue is suitable education and training programs - current engineering curricula prepare students neither for the increase in heterogeneity in dimensions and materials, nor for the increased manufacturing complexity.

Equally, modelling and simulation tools need to be available - not only for corporate use, but also for institutions of higher education to execute the demanded training activities.

For heterogeneous components and integrated systems, with their high degree of functionality and complexity, benchmarking and mapping activities will be needed (also internationally) to lead to a catalogue of best practices.

CONCLUSIONS

The workshop dealt with Europe's capability to master the use of the new technologies to move from the laboratory to the fabrication of customised and large scale production of miniaturised ICT components, devices and systems. Due to the complexity of the field, the broad objectives and the inter-related priority areas identified have been structured in a matrix. In every "box" of the matrix the main critical topics to be addressed in the future research plans have been identified. The emphasis depends on the maturity of the technology and manufacturing, on volume and nature of the market, industrial structure (SMEs, start-ups, large companies and single fab lines), on the level of complexity and multi-disciplinarity, and on European strength and opportunities. Orthogonally to this the applications sectors also will modulate the different needs and the European position in different blocks. This matrix of opportunities may need some further tuning towards optimum chances for European added value and impact. Common issues were also defined.

ANNEX 1: MATRIX OF OBJECTIVES AND PRIORITY AREAS

| Functionality increase from left to right | Micro-/Nano-electronic devices (1) | | Heterogeneous components (2) | Integrated systems (3) | |
|---|---|---|---|---|---|
| | Single fab line Monolithic / Complementary technology | | Multiple lines Multi-processes | Assembly lines / System Integrators | |
| | High volume, commodities | Customized / lower volume / higher value | | High volume, lower cost | |
| Production Management | Factory optimization for efficiency & cost | Efficiency versus flexibility/cost | Flexibility, modularity and cost | Efficiency versus flexibility / cost | Efficiency of production & cost |
| | * automation * equipment utilization * data & support management | * re-use equipment, * customer relationship | * standard interfaces * customer & cooperative management | * customers relationship * IPR | * reliable, stable production *automation |
| Design for Manufacturing | Design for test Design for Reliability Design for optimum yield (DfM) | | Self test, Design platforms & Factory customisation Design modularity | Self test, Design platforms Functional test & specific application needs | |
| Metrology, failure analysis | Physics of failure small dimension In-situ & atomic scale metrology Process control, Fault detection & classification, Material & performance characterization tools | | Physical / non- electrical properties Physics of failure & performance of new material & mix of scientific fields 3D- challenge | Modular: high throughput/ low cost control system (high volume) Systems & reliability verification, physics of failure Specific demands for specific applications / environments | |
| Equipment & manufacturing processes | Automation Simulation Reduced dimensions Surface & 3D engineering New materials Wafer level packaging Interface nano- devices Prepare for 'bottom-up" self assembly techn. | Capitalize on progress in high volume manufacture Flexibility Re-use | From prototyping into industrial equipment and manufacturing 3D manufacturing issues Interface, packaging & interconnect solutions (SiP) Wafer level packaging Micro-position handling | "Mesoscopic gap" 3D structures, 3D stacking Packaging, assembly technologies High precision assembly Application specific tools Self-assembly | Automation From prototype into industrial production Disruptive technologies: R2R, printing, polymer |
| Commercialization & Infrastructure | RTD to include industrialization phase at all stages Support services for SMEs: small volume shared production & analysis | | | | |
| | Quality tracking & contamination control Extend lifetime of installed base Distributed facilities Equipment assessment | | Incubator structures Technology assessment on manufacturability New cooperative business models | Incubator structures Technology assessment SME support services (application / environmental specific requirements) SME support services for IPR protection and to address global market; financing starting-up, ... | |
| Support measures | Standardization (process control & monitoring, equipment) Education & training Modeling & simulation International Roadmaps | | Standardization (process, modules & interfaces) Education & training Modeling & simulation Benchmark, best practice | Standardization (interface, modules, subsystems), Education & training Modeling & simulation Benchmarking, Roadmapping, Best practices, | |

- (1) Includes also the above IC processes of MEMS, passive devices, etc... to realise the Systems on Chip in one fabline, resulting in monolithic integrated devices.
- (2) Includes also the hybrid integrated components as System in Package or Microsystems mostly realised using different fablines.
- (3) Includes multi-component miniaturised assemblies as well as integrated (sub)systems using miniaturised ICT and small dimensional technology as main driver for their functionality e.g. polymer electronics and other polymer devices, lab cards, integration in smart textile, smart packages, etc....

ANNEX 2: AGENDA

FP7 Workshop
NEW MANUFACTURING TECHNOLOGIES FOR
MINIATURISED ICT

22 February 2005
European Commission
Avenue de Beaulieu 24, room 0/83, Brussels

AGENDA

- 09.00-09.30** **Registration and welcome**
Hosts: G. Kelm and A. Sánchez
- 09.30-09.40** **Workshop objectives**
Speaker: Dirk Beernaert (European Commission, Head of Unit)
- 09.40-11:50** **Presentations by participants (7 minutes, 2 slides) (*)**
Chairman: H. Schumacher (Univ. of Ulm)
What should be the objectives and the research priority areas for bringing the new technologies into the manufacturing of miniaturised and integrated ICT devices and micro-nanosystems?
- 11.50-12:30** **Identification of the objectives and the priority research areas**
Chairman: H. Schumacher
- 12.30-13.30** **Sandwich lunch**
- 13.30-16.00** **Identification of the research initiatives under every priority area**
Chairman: A. Richardson (Univ. of Lancaster)
What are the main roadblocks and opportunities? What should be the research initiatives to be recommended?
- 16.00-16.30** **Coffee break**
- 16.30-17.00** **Summary and conclusions**
Speakers: A. Richardson and H. Schumacher
- 17.00-17.05** **Wrap-up**
Speakers: G. Kelm and A. Sánchez
- 17.05** **End of the meeting**

ANNEX 3: PARTICIPANT'S LIST

| Family Name | First Name | Organisation Name |
|--------------------|-------------------|--|
| Richardson | Andrew | Univ. of Lancaster |
| Harder | Thomas | ECPE |
| Da Vigna | Benedetto | ST Microelectronics |
| Coello-Vera | Agustin | ALCATEL SPACE |
| Van Rossum | Marc | IMEC |
| Schumacher | Hermann | Univ. of Ulm |
| Kopola | Harri | VTT |
| Mangas | Juan | COTEC |
| Gløersen | Per | SensoNor AS |
| Grabiec | Piotr | ITE |
| Schmitt | Jacques | UNAXIS |
| Dommann | Alex | CSEM |
| Jongerius | Michel | PHILIPS |
| Pfitzner | Lothar | Fraunhofer IISB |
| Ratchev | Svetan | Univ. of Nottingham |
| Van Eck | Brad | ISMI - International SEMATECH Initiative |
| Kergel | Helmut | VDI/VDE |
| Wach | Max | JEMI-France |
| Kennedy | Barry | INTEL Ireland Ltd. |
| Babikian | Richard | INTEL Ireland Ltd. |
| Beernaert | Dirk | European Commission |
| Van Caenengem | Griet | European Commission |
| Boukerche | Marc | European Commission |
| Filos | Erastos | European Commission |
| Santos | Jorge | European Commission |
| Lymberis | Andreas | European Commission |
| Kelm | Georg | European Commission |
| Sánchez Grueso | Alejandro | European Commission |