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Study About The Micro-Manufacturing

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Abstract

Micro manufacturing has emerged as a critical area of study and research, driven by the growing demand for miniaturized devices and components in various industries.This paper presents an overview of the theory behind micro manufacturing, focusing on the key principles, processes, and challenges associated with producing microscale components.Micro manufacturing is rooted in the fundamental principles of traditional manufacturing processes, but with a focus on scaling down these processes to produce components with dimensions ranging from micrometers to a few millimeters.This scaling down presents unique challenges related to material behavior, process control, and tooling, which require a deep understanding of the underlying physics and mechanics.One of the key processes in micro manufacturing is micromachining, which involves cutting, milling, and drilling at the microscale.This process requires specialized equipment and tooling, as well as advanced control systems to achieve the high precision and accuracy required for microscale components.Other important processes in micro manufacturing include microforming, micromolding, and microassembly, each with its own set of challenges and considerations.Materials play a crucial role in micro manufacturing, as the properties of materials at the microscale can differ significantly from their macroscopic properties.Understanding these differences is essential for selecting the right materials and processes for microscale components.Additionally, the integration of different materials and technologies, such as electronics and MEMS, adds another layer of complexity to micro manufacturing.One of the key challenges in micro manufacturing is achieving high throughput and efficiency while maintaining high precision and quality.This requires the development of new processes and technologies, as well as the integration of automation and robotics to streamline production processes.Additionally, the design of microscale components plays a crucial role in their manufacturability, requiring a multidisciplinary approach that integrates design, materials, and manufacturing considerations.the fundamental principles, processes, and technologies involved in the design, fabrication, and operation of electronic devices and circuits at the microscale.This abstract provides an overview of key aspects of microelectronics theory, highlighting its significance and applications in modern technology.At the heart of microelectronics theory lies semiconductor physics, which governs the behavior of electronic devices based on semiconductor materials such as silicon.Understanding the principles of semiconductor physics, including carrier dynamics, band theory, and device operation, is essential for designing and optimizing microelectronic devices.The fabrication of microelectronic devices involves a series of intricate processes, collectively known as semiconductor manufacturing or semiconductor fabrication.These processes include photolithography, etching, deposition, and doping, among others, and are carried out in specialized facilities known as cleanrooms.The goal of semiconductor fabrication is to create complex patterns and structures on semiconductor wafers with nanometer-scale precision, allowing for the integration of millions or even billions of transistors on a single chip.Transistors are the building blocks of microelectronic circuits and are responsible for amplifying and switching electrical signals.In microelectronics theory, various types of transistors are studied, including metal-oxide-semiconductor field-effect transistors (MOSFETs), bipolar junction transistors (BJTs), and complementary metal-oxide-semiconductor (CMOS) transistors.These transistors form the basis of digital logic gates, analog amplifiers, and other electronic circuits.The miniaturization of electronic components and circuits, made possible by advancements in microelectronics theory and fabrication techniques, has led to the development of increasingly powerful and energy-efficient electronic devices.Microelectronic devices are ubiquitous in modern technology, found in smartphones, computers, medical devices, automotive systems, and countless other applications.In addition to traditional silicon-based microelectronics, emerging technologies such as flexible electronics, organic electronics, and quantum computing are expanding the scope of microelectronics theory.These technologies offer new opportunities for creating innovative devices with unique properties and functionalities, paving the way for the next generation of electronic systems.

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I. Introduction

Manufacturing, as a general term referring to industry, is to make products that have been designed for certain applications.The meaning of ‘manufacture’ has, however, changed, especially during the last 20 years, in terms of what is being made, how it is made, how manufacturing is organized, etc.Manufacturing has been influenced not only by the increased demands on producing routine products and creating new pro ducts but also by social, economic and even polit ical changes.The desire for a better quality of life, good health and high working efficiency has been one of major drives in the innovation of many products, such as new models of computers, cars, mobile phones, CD players, MP3 players, wide flatscreen displays, medical instruments/ implants, etc.Dramatic changes in global, eco nomic development during the last 15 years have significantly influenced how manufacturing is organized and implemented, e.g.new concepts concerning supply chains, new patterns for colla borations, etc., to such an extent that in a lot of cases, how to organize manufacturing becomes even more important than how the products are to be manufactured.How to achieve a balance between quality and cost is another major issue, since many industries are fighting for survival.Nevertheless, some general issues still apply to all sectors concerned, e.g.issues on how to quickly deploy new technologies and management methods to improve manufacturing capability, efficiency and quality, no matter whether they belong to traditional, developed countries/regions or developing countries/regions.For the developed countries to compete with lowcost production, the manufacturing industry will need more innovations and changes of the focus.Reducing the cost by significantly improving efficiency and supply chains, maintaining technological advantages by continuously developing leading technologies/ capabilities, and delivering higher quality and innovative products are being pursued.For the developing countries, lowcost manufacturing may only be a shortterm solution and not the ultimate goal, as this will have limited impact/ effect in the long term.From these considerations, as a contribution to competitive manufacturing, this article provides a useful reference for the manufacture of emerging miniature/microproducts, especially for improving massmanufacturing capabilities and their applications for the manufacture of these products.There are ever increasing demands on miniaturized/micro products/systems and components, e.g.MEMS (microelectricmechanical systems) and microsystems, microreactors, fuel cells, micromechanical devices, micromedical components, etc., which are now popularly used in vehicles, aircraft, telecommunication and IT facilities, home appliances, medical devices and implants.Manufacture of these products has received great attention during recent years.At the same time, as nanotechnology becomes more and more mature and influential, more nanotechnologybased products have emerged, such as nanodevices for sensors, communication and medical treatment, nanomaterials and coating/functionalized surfaces for enhanced performances, etc.To make these products in a volume production scale, effectively linking macroand nanoworld.Manufacturing is essential.Micro-manufacturing is the bridge between macromanufacturing and nanomanufacturing.Micro-manufacturing concerns manufacturing methods, technologies, equipment, organizational strategies and systems for the manufacture of products and/or features that have at least two dimensions that are within submillimeter ranges.Micro-manufacturing engineering is a general term which concerns a series of relevant activities within the chain of manufacturing microproducts/features, including design, analysis, materials, processes, tools, machinery, operational management methods and systems, etc.There is a huge diversity in microproducts, the main types being microelectronics products, microoptical electronics systems (MOES), microelectronics mechanical systems (MEMS) and microoptical electronics mechanical systems (MOEMS), depending on the combinations of product functionalities and/or working principles.Correspondingly, there are different methods and strategies which could be used to manufacture these products.Micromanufacturing, in a wider context, should cover all these aspects.Relating to manufacturing these products/features.The definition of micromanufacturing, or its gravity/focus, often varies from different sources.There is an enormous amount of literature on the manufacture of MEMS and microsystems.The technologies relating to design and fabrication of these microsystems are sometimes referred to either as microsystem technology (MST) or MEMS techniques.In order to differentiate from other manufacturing techniques, Micro-manufacturing techniques are often categorized respectively as MEMS manufacturing and nonMEMS manufacturing.MEMS manufacturing involves, largely, techniques such as photolithography, chemical etching, plating, LIGA, laser ablation, etc.while nonMEMS manufacturing often involves techniques such as EDM, micromechanical cutting, laser cutting/patterning/drilling, microembossing, microinjection molding, microextrusion, microstamping, etc.Regarding the materials used, Micro-manufacturing is also sometimes categorized as siliconbased manufacturing and nonsilicone material manufacturing.The purpose of differentiating these is sometimes to emphasize the importance of the latter as an urgent need for development, since siliconbased manufacturing is often seen as a ‘mature’ business.For people who are involved in MEMSbased manufacturing, Micro-manufacturing may be not a new term, as they may feel that manufacturing various MEMS has been undertaken by industry for many years, which has also been performed at volumeproduction scales.For people who are newly engaged in nonMEMSbased manufacturing, Micro-manufacturing is somehow seen as a recently emerging field of significant challenges.This is not only because manufacturing will have to deal with much wider ranges of materials, which cannot be handled by traditional MEMSbased manufacturing techniques alone, but also because scaling down the processes, tools and machinery from conventional ones such as mechanical/thermal cutting/forming to meet the needs of achieving much smaller dimensions and sophisticated features is new and extremely challenging.In this sense, the emerging Micro-manufacturing techniques often refer to nonsiliconbased and even nonMEMsbased manufacturing.A new definition of micromanufacturing, therefore, may be the ‘manufacture of microproducts/features with scaleddown conventional technologies/processes.These include processes such as micromachining (mechanical, thermal, electricchemical, electric discharge methods), microforming/replication, microadditive (rapid methods, electroforming, injection molding, etc.) and joining.Another focus of Micro-manufacturing is the manufacture of products/components with miniature machines/systems, rather than conventional, largescale machines/systems.This article is focused on the description of nonsiliconbased manufacturing, especially nonMEMS manufacturing techniques and systems, although there are several chapters dealing with the techniques for both MEMS and nonMEMS manufacturing.This chapter is intended as an introduction to micromanufacturing.

II. Microproducts And Design Considerations For Manufacturing

Typical microproducts include MEMS and microsystems for automotive and aerospace use such as pressure sensors, thermal sensors, temperature sensors, gas sensors, rate sensors, sound sensors, injection nozzles, etc., and the components include those for electrostatic, magnetic, pneumatic and thermal actuators, motors, valves and gears [1].The products also include sensors for mass flow, microheat exchangers, microchemical reactors, tools/molds for forming/replication, etc., and the components include those for miniaturized electronics products such as mobile phones, MP3 players, CD players, iPods, etc.In the medical sector, the microfabricated parts span a wide range for implantable applications in various clinical areas.There are 94 active and 67 commercial ‘end items’ out of a total of 142, according to the literature [2].Typical examples are sensors for cardiovascular, micromachined ceramic packages, implantable devices, coatings on micropolymers or metal parts, etc.It is fair to say that microproducts and components are almost everywhere in our lives.Design of products for Micro-manufacturing needs to address production issues fully, compared with the prototype products based on microtechnologies.High volume production of microcomponents should be a target for design for micromanufacturing.When these products are designed, not only will functional requirements need to be considered but also Micro-manufacturing related factors will have to be taken into account.This is because, as briefly described above, manufacturing these products renders more significant challenges, compared to the manufacture of macroproducts.The following are some typical issues to be addressed at the design stage:

Overall dimensions of the parts/products:

Overall dimensions of a part/product, like diameters, widths, lengths and thicknesses, are very much constrained by the overall capabilities of the processes and manufacturing facility (machines, handling devices, tools, etc.).Both maximum and minimum dimensions are the parameters to be checked with reference to the manufacturing system’s capabilities.Complexity around dimensional scale issues is a dominant factor in micro/nanomanufacturing.The question often asked may be how small rather than how large a part can be handled.

Part/component local features:

design of local Features, such as hole/pocket radii and aspect ratios, widths/depths of channels or aspect ratios, wall thickness, area reductions, density of the local features, will be largely constrained by the processing capability in micro/nanomanufacturing, especially those relying on the use of tools such as replicating processes.There is also the factor of relevant grain size effects of the material to be used.Local features will not only determine the tool geometry, but also affect stiffness/rigidity of the part/product structures, and hence affect the manipulation.Of the part/product.Manufacture of local features spread over a large area also renders challenges to many Micro-manufacturing processes and equipment, even nanomanufacturing.

Shape capability:

Shape capability considers the capability/limitation of a manufacturing process in dealing with the shapes to be produced.For example, a lot of processes are only able to deal with 2D/2.5D shapes while 3D shapes may need much more significant efforts such as new processes and expensive equipment.

TABLES:A:Presents some examples of the products/parts which can be made with microfabrication techniques, particularly with mechanical and/or thermal Micro-manufacturing processes.

Components/ Parts	Simple Geometry /features	Possible Enabling Techniques	Typical Part Materials	Processing Accuracy	Typical Products/ Applications
Surface 2.5D functionalized structures	**Local features in hundred**	**Hot embossing/coining/ imprinting, inkjetting,**	**Polymers, glass aluminum**	**Several microns to nanometers**	**Microoptical, fluidic devices, force**

	nanometers to 10s of microns	**plating, direct writing, laser ablation, etc.**	**copper, brass, steel, etc.**		**transmit.Surfaces , dies/ molds, etc.**
Lead frames	**Various geometry, local features as small as ten microns, thicknesses vary, such as between 0.3 and 0.01 mm.**	**Microstamping, with/ without laser assistance, laser cutting, photochemical etching, etc.**	**Copper and alloys, nickel steel, etc.**	**Several microns or to 10% of the sheet thickness**	**Electronics.Products.**
Micropins	**Diameters in 0.21 mm ranges, wall thickness in 50 to 200 microns possible, and tolerances <5 microns**	**Forward, and/or combined with backward extrusion, microshape rolling, micromachining/EDM.**	**Various types of metals**	**Several microns to submicrons**	**Various applications as IC carrier, microdevice assembly, electric contacts, etc.**
Electrothermalmechanical actuator	**2.50/30 structural parts, various sectional geometries**	**Chemical etching and microstamping, laser cutting, efab.**	**SMA and other metal materials**	**Several microns**	**Microactuating devices**
Microcups	**Microcups, less than 1 mm in diameter, various thicknesses**	**Microdeep drawing.Microstamping, microspinning, micromachining.**	**Molybdenum, copper, aluminum, steel**	**Several microns**	**Electron guns, pressure sensors, UV sensors, etc.**
Microgears	**Diameters of 1 mm or less, local features in 10s of microns**	**Microforging, microextrusion, microstamping, LIGA, microcasting, PCE.MicroEDM, efab, etc.**	**Metals polymers**	**Several microns to submicrons**	**Micromechanical Device Watches**
Shafts for micromechanical drivers	**Less than 1 mm in diameters**	**Microextrusion, micromachining/EDM**	**Steels and alloys**	**Several microns to submicrons**	**Microdrivingdevices, e.g. Microspindles**
Microscrews, microcans	**Diameters in 0.10.5 mm ranges**	**Microforging, extrusion, shape rolling, micromachining.**	**Various metals**	**Several microns to submicrons**	**Microdevices, housing and assembly, etc.**
Microgear shafts	**Local features in 3050 microns**	**Extruded with local heating, microradial extrusion, micromachining, EDM.**	**Metals**	**Several microns to submicrons**	**Micromechanical driving devices, watches**
Casing/housing of microdevices	**Thin sheets, from 0.1 to 0.01 mm**	**Microstamping, dipping, drawing, hydro forming.**	**Stainless steel, aluminum, copper, etc**	**Several microns**	**Micromechanical, electronics, medical, optical, chemical devices, etc**
Microtubular components	**Outer diameters less than 1 mm, wall thickness larger than 20 microns**	**Microhydrotubeforming, microrolling, microbending, laser machining, etc**	**Metals**	**Several microns**	**Microshafts, microheat exchangers, micromedical devices/implants**
Micromolds, dies and punches	**Diebore or inner pockets in less than 1 mm; punch**	**MicroEDM, lasercutting, micromachining, electroforming, sintering, etc**	**Tool steels, glass, powder, etc.**	**Several microns to submicrons**	**Forming/ replicating processes, e.g.injection molding,**

	diameter from 0.05 to 1 mm				**embossing, extrusion, etc.**

Extrusion, for example, considering the effects of grains and grain sizes on the process.Any asymmetry may create difficulty in controlling the quality in microshaping.Excessive material accumulation, large reductions in area and sudden changes of the sections should also be avoided in forming/shaping.Others include the design of the draft for the workpiece for microforging, permitted drawing ratios and profiles of the drawn products in microsheet forming, etc.Conventional rules on shape capability of manufacturing may not be applicable to Micro-manufacturing largely due to the sizes to be considered and limitation of the tool shapes that could be produced.

Tolerance and surface quality capability:

design of a macroproduct would expect the designer to consult handarticle s/standards before specifying a grade of tolerance and surface quality requirements.Design for Micro-manufacturing may not be as straightforward as the design of a macroproduct.Standards on manufacturing tolerances for design for micromanufacturing, especially for nonMEMSbased manufacturing, have not been established fully, while most of the data is ‘inhouse’ determined/used.The designer may have to consult with the manufacturing engineers who are responsible for their own manufacturing capability.

Material capability:

selection of a material for Micro-manufacturing will be constrained.Largely by availability of the material for volume production, due to the limited number of the suppliers currently operating in this field; however, the trend is improving, such as with nanomaterial suppliers, the number of which has increased significantly recently.New study/ qualification of material properties may be needed if the material suppliers are not able to provide the material data relevant to micromanufacturing, such as size effects and material property descriptions.The properties will have to be qualified for design uses, with consideration of size effects, and these have to be available with the inclusion of mechanical, thermal, electrical and magnetic properties, as appropriate, and others including biocompatibility, chemical compatibility, hydrophile and Hydrophobe properties, etc.Grain sizes of the material to be selected must also be known for most of the Micro-manufacturing processes.Ultimately, the designer has to know which processes are most suitable for the materials selected, or materials suitable for available processes, etc.

Part/component material properties after processing:

involvement of large plastic deformations, damages, possible significant local temperature rise and thermal stresses during mechanical and thermal processes may, very likely, result in alteration of the material properties after processing.The micropart/ component material properties will play significant roles in determining part/component performance under working conditions than that for macrocomponents, such as those used in microsensors and medical implants.Part/component design is, therefore, constrained by the applicability of certain Micro-manufacturing processes, e.g.chemical and high temperature processes, due to considerations of possibly adverse effects on the material properties.

Characteristics of volume production:

The design should also address significant characteristics of volume production in micromanufacturing.Prototyping in a lab scale is significantly different from manufacturing the products in a productionscale.Achievable/targeted production yield, which is prescribed largely by the capability of the processes, machinery, tools and auxiliary equipment, will have an influence on the selection of the materials for manufacturing and design of the part/ component and its features.Among those factors, handling the parts/components and interactions with tools are particular concerns that should be taken into account at the design

Stage.Manufacturing cost:

Manufacturing cost is a major issue to be addressed.This is largely because Micro-manufacturing often involves high investment in facilities and human resources and low product quantity requirements from each customer.Many factors prescribe the manufacturing cost, and a balance, However, will have to be maintained between the feasible reduction of the cost for core processes and the cost involving the use of auxiliary processes.Some sophisticated geometry and tight tolerances may not be achievable solely with a single process, and using a process chain which may involve various processes is often inevitable.The designer has to be aware of how the design specifications will impact on planning for the manufacturing chains.He/she has to realize that the cost for tooling for some Micro-manufacturing processes may.Be very high.A comparison among available.Manufacturing processes/chains and even involving supply chains may be needed, even at the design stage.

Synthesis factors:

Design synthesis may be conducted by considering all factors discussed above.The results can be a basis for design optimization.Strong dependences of the component/part design on the manufacturing processes in Micro-manufacturing suggest that design iterations and interactions with manufacturing personnel are often inevitable and necessary.The design of microproducts is still a challenging task due to lack of sufficient standards, design/ manufacturing rules and understanding of the manufacturing processes themselves.There is also a lack of effective software to support the design activities.Incorporating size effects into conventional design and analysis software and/or developing domainspecific design and analysis tools (software) will help to improve the situation.Modeling for different length scales such as micromechanics modeling, molecular dynamics modeling and multiscale modeling, and integration of these into commercial software, are urgent needs for design for micromanufacturing.Some of these will be mentioned in several chapters of this article .

III. Material Factors

Material properties have much more significant impact on the design/planning for micromanufacturing, compared to that in macromanufacturing, which, for example, is reflected in the following aspects:

- Size effects on mechanical, thermal, electrical and magnetic properties, biocompatibility and chemical compatibility, hydrophile and hydrophobe properties, etc.need to be understood, and some of these may be significantly different, compared to the material behaviors in the macroscale.
- As a consequence of the above, mechanisms of material conversion processes (separation, deformation, joining/deposition chemically.And physically) will be different or affected, as well as interactions between the materials and processing tools (for toolbased processes).
- As a consequence of the above, selection of the means for enabling material convention.Processes will be affected, the considerations including effectiveness and efficiency and effects on the material properties of the processing methods (mechanical, chemical, thermal, electricchemical methods, etc.).
- Grain and grain boundaries, which may have less impact on the material conversion processes in macromanufacturing, will have a more significant impact on the material conversion mechanisms as the dimensional scale decreases and the sizes of the grains become more relevant, such as influence on the interfacial friction and dislocation of grains and damages.This is particularly relevant in mechanical material conversion processes.
- Emphasis on the importance of the materialrelated issues in Micro-manufacturing is also due to lack of sufficient, effective means for qualifying some material properties in the microscale, and hence insufficiently understanding these.

In design and planning for micromanufacturing, special attention should be given to the microstructures of materials such as grain sizes, grain boundaries, precipitations and intermetallics as second phase particles and their size and distribution in multicrystalline structures, against the sizes of microproducts/features (less than 1 mm in dimension).Developing new materials and increasing volume of the materials available for particular Micro-manufacturing processes are needed: otherwise, Micro-manufacturing will be constrained significantly by the limited number of the materials which could be processed in the microscale with the required quality and efficiency.A typical example is that the type of the materials usable in microreplication/forming processes is quite limited by material flowability, strength, hardening and surface adhesive behaviors.For a volume production, fine grains and high plastic flowability of the material either at room temperature or at elevated temperature are preferred.The following are some examples of the materials used in micromanufacturing: materials with finer grain sizes; alloying of elements with high purity grades; modification of surface roughness, e.g.laser defined microstructured surfaces; materials with defined strain hardening; materials originated from galvanic processes; single crystal material with monocrystalline structure; materials by thin wire processing, e.g.bond wires for microelectronics; materials by thin foil precision cold rolling; materials with special coatings; materials with total or selective plating of strips; materials for thin film coating; materials for roll cladding strips; etc.

IV. Considerations On Manufacturing Methods

Compared to the manufacture of macroproducts, manufacturing methods and strategies in Micro-manufacturing may be different.Manufacturing macroproducts may be carried out by manufacturing individual components/parts by removing and/or deforming and/or adding materials, and then assembling them.These can be carried out either at a single industrial site or at different sites.Manufacturing microproducts may be carried out with patterning, deposition and layering methods within a single machine/manufacturing platform, e.g.integrating components/parts fabrication with assembly/packaging is often used in MEMS and microsystems manufacturing.Micro-manufacturing largely uses nontraditional manufacturing methods or scaling down or modifying the traditional methods, as appropriate, to fully address issues related to manufacturing in the microworld.Further, manufacturing chains may also be different, compared to traditional manufacturing.These may be due to:

Material property:

Conventional manufacturing methods may not be able to cope with special material properties, e.g.either too hard or too weak for a process, sticking onto microtools, not compatible to the mask materials, or original material properties cannot be altered during manufacturing, e.g.affected by mechanical workinduced heat or direct heating processes, etc.

Structural strength and stiffness:

components/ parts may be too fragile to sustain any mechanical forces needed for processing materials, or too difficult to handle during processing and/or assembly/packaging.

Shape and sizelength scale factors:

all factors associated with small dimensional scale manufacturing apply, e.g.inability of tool fabrication for mechanical cutting and plastic forming may force the consideration of nonmechanical approaches.Normal geometric shapes such as holes, slots, pockets, threads, etc.may not be a problem in macroscale manufacturing, but these may be extremely difficult to achieve if the dimensions decrease to submillimeters.Alternative manufacturing methods to conventional ones such as patterning, deposition and layer manufacturing methods may have to be considered.

Difficulties for clamping/releasing:

Due to the sizes and structuring strength/stiffness issues, it may be difficult to clamp/release the components/parts to be made by mechanical manufacturing methods such as mechanical cutting and forming.Alternative methods such as laser ablation, electroforming and chemical etching may be considered.

Residual stress and surface integrity:

existence of the residual stresses and weakened surface integrity, induced by plastic deformations, cyclic loadings, thermal gradients, etc., may not be acceptable for some critical components/parts for microproducts, e.g.those for medical implants and high grade sensors.Selection of processes may have to consider such issues and process chains may have to be optimized to address these issues.Fundamentals of the roles that the reduced length scales could play in various processing mechanisms need to be understood, e.g.roles of the surface at different length scales and in different manufacturing processes with respect to surface fabrication and micro/nanomanipulation, surface metrology, etc.[34].These play a significant role in selecting manufacturing methods and in optimizing the manufacturing chains.

V. Manufacturing Methods And Processes

Both conventional and nonconventional methods have been used to manufacture microproducts.There have also been emerging methods.Such as hybrid manufacturing.According to the type of energy to be deployed, manufacturing may be classified as mechanical, chemical, electrochemical, electrical and laser processes.The working principles include mechanical forces, thermal, ablation, dissolution, solidification, recomposition, polymerization/lamination and sintering [5].According to the way in which the components/products are to be made, general manufacturing processes can also be classified into subtractive, additive, forming, joining and hybrid processes.The classification is equally applicable to micromanufacturing.Typical manufacturing methods for producing components/ products are as shown in Table AB.Some typical Micro-manufacturing methods/ processes are detailed in this article .The following texts give an overview of some key methods and processes, as well as the current state of the development.

Mechanical Machining:

Mechanical machining is a technology that has been widely investigated in the field of precision engineering.Micromachining may be seen as an ultraprecision material removal process which is

Table:B:Typical Methods/Processes of Micro-manufacturing (edited based on a table presented in [5])

Subtractive processes	Micromechanical cutting (milling, turning, grinding, polishing, etc.); microEDM; microECM; laser beam machining; electro beam machining; photochemical machining; etc.
Additive processes	Surface coating (CVD, PVD); direct writing (inkjet, laserguided); microcasting; microinjection molding; sintering; photoelectroforming; chemical deposition; polymer deposition; stereolithography; etc
Deforming processes	Microforming (stamping, extrusion, forging, bending, deep drawing, incremental forming, superplastic forming, hydroforming, etc.); hotembossing; micro/nanoimprinting; etc.
Joining processes	Micromechanicalassembly; laserwelding; resistance, laser, vacuum soldering; bonding; gluing; etc.
Hybrid processes	MicrolaserECM; LIGA and LIGA combined with lasermachining; microEDM and laser assembly; shape deposition and laser machining; efab.; laserassisted microforming; microassembly injection molding; combined micromachining and casting; etc.

Able to achieve microform accuracy and several nanometer finishes [6].From precision machining to micromachining, some challenging issues are met such as predictability, producibility and productivity in microscale manufacturing [7].It may be difficult to achieve complex 3D, intricate microfeatures/components with mechanical micromachining, although it is still a powerful technology in developing microcomponents for various systems such as those operating on electronic, mechanical, fluidic, optical and radiative signals [8], e.g.the systems for microinstrumentation, inertial sensing, biomedical devices, wireless communication, high density data storage, etc.as well as producing dies and molds for other manufacturing processes such as microforming and injection molding [6].Due to the working principle of removing chips by mechanical forces, significant efforts have been devoted to the improvement of the precision of machine tools and development of errorcompensation methods to ensure the required precision of the machinetoolworkpiece system.Main issues addressed include understanding of chip formation mechanisms and micromachining mechanics, machine tool design with 'optimal' dynamics stiffness, optimal cutter geometry/materials and motion control, inprocess inspection with high resolution metrology, etc.[6].The trend for benchtop machine tool designs has now shifted from largescale, ultrahigh precision designs to miniature structures and low cost system designs.Ultrahigh precision and high speed spindle design is another topic attracting many researchers and industries.Diamond cutting tools, tools with nanocrystalline diamond coating [9], etc.are also important in micromachining.

MicroEDM:

Electrophysical and chemical micromachining processes play important roles in Micro-manufacturing due to their special material removal mechanisms [10].Electricaldischargemachining (EDM) is especially suitable for manufacturing microcomponents/tools due to its thermal material removal mechanism, which allows almost process forcefree machining independently of the mechanical properties of the processed material.High precision EDM can process functional materials like hardened steel, cemented carbide and electrically conductive ceramics with submicron precision [11].Its applications have extended far beyond dies/molds fabrication such as microgears, microfluidic devices, medical implants, etc.The processes include microwire electrical discharge machining, micro die sinking, microelectrical discharge drilling, microelectrical discharge contouring and microelectrical discharge dressing.Compared to conventional EDM.

- Places more emphasis on the following: Precision of the machine, e.g.high precision control of the motion of the electrodes.
- Qualification of the wear of the electrodes, damage on the wire, and compensation for the wear/damage.
- Careful control of the frequency of discharge, level of the energy input, e.g.current and voltage.
- Better understanding of material properties, thermal conduction of the workpiece, melting and recasting processes, and their effect on the surface finish/integrity.
- Careful considerations of the setup of gaps, component forms to be produced, flash of the debris, etc.

Besides the miniaturization of the tool electrodes, compared to conventional EDM, the minimum discharge energy of 0.1 μJ is obtainable, which causes only very small material removal at one single discharge.This results in an extremely small gap width ranging from 1.5 to 5 μm [11].To achieve a reasonable material removal rate, spark generators which are able to produce extremely high impulse frequencies have to be used, e.g.capable of impulse frequencies of up to 10 MHz.

Microelectrochemical Machining (MECM):

ECM is another popular choice for making microparts, due to less effort needed for handling during the ECM, easy control of the process, relative simplicity in machine design/setup (CNC possible) and the capability to process various materials, including high strength materials.Other attractive characteristics include burrfree surfaces, no thermal damage, no distortion of the part and no tool wear.The issues needing to be addressed in Micro-manufacturing applications include controlling material removal, machining accuracy, power supply, design and development of microtools, roles of interelectrode gap and electrolyte, etc.[1213].High surface roughness, relatively poor fatigue properties, difficulty to make sharp corners, etc.are some negative aspects to be taken into account when considering this process for manufacturing.For micromachining, masks may be used (one side or two sides possible) for making finer geometry.For precision manufacturing, a pulsed power of relatively short duration (about 1 ms) may be used, which may enable shorter interelectrode gaps (<50 μm) to be utilized.These small gaps with good process control could yield accuracies of the order of ±1 μm on 50 μm and surface roughness of R, 0.03 μm.

Microforming:

Microproducts may be produced with forming configurations, i.e.microforming.Metal forming offers some attractive characteristics that are superior to those of other processes, e.g.machining and chemical etching, considering such features as higher production rates, better material integrity, less waste, lower manufacturing costs, etc.Various forming/forging configurations are possible such as forging, extrusion, stamping, bending, hydroexpansion, superplastic forming, etc.Microforming may be achievable by effective scaling down of the process configurations, tools and even machines [1417].Some challenges do arise when the sizes/features reduce to tens or hundreds of microns, or the precision requirements for macro/miniature parts reduce to less than a few microns.Major issues to be addressed.Include understanding of material deformation mechanisms and material/tool interfacial conditions, materials property characterization, process modeling and analysis, qualification of forming limits, process design optimization, etc., with emphasis on the related size effects.The following observations have been established based on a series of studies and RTD efforts:

- Conventional metalforming process configurations such as forging, extrusion, stamping, coining, deep drawing, etc., may be equally used for the forming of miniature/microparts; process capabilities are likely to be constrained further due to additional material and interfacial and tooling considerations in microforming.
- The types of materials which could be formable at the microlevel are prescribed more significantly than for forming at the macrolevel by the microstructures and grainboundary properties of the materials.The forming limits for these materials are, therefore, somewhat different, compared to those for the forming of macroparts.
- Size effects may exist in material property and tool/material interfacial property characterization, depending largely on the microstructures of the materials, which lead to the requirement of the definition of these parameters with reference to the actual materials and interfaces to be used.
- Machines, forming tools and handling devices are critical in the industrial applications of microforming technology..

Some traditional forming machine designs may be scaled down for microforming needs, as long as the machines are able to cooperate with the use of microtools of acceptable quality and efficiency.However, more particular considerations will have to be incorporated into machine design to meet engineering applications requirements, e.g.greater precision, handling of microparts/ materials with higher rates and positional precision, etc.[1820].Several chapters of this article deal with the machine development for microforming, the results taken from an EUfunded projectMASMICRO [1617].Applications of the microforming technology also rely largely on the development of microand even nanomachining technologies.The latter is key to the fabrication of microtools and the preparation of micromaterials.

Laser Technology:

Laser technology is qualified as an efficient microtechnology because of its high lateral resolution by minimized focusability down to a few microns, low heat input and high flexibility.One major advantage is its capability of processing various, nonsilicon materials that are increasingly needed for manufacturing microproducts.Some examples for laser applications are microcutting, microdrilling, microwelding, soldering, selective bonding, microstructuring and laser assisted forming [21].Femtosecond laser micromachining is a new approach emerging in the MEMS area, and some promising results have been shown in micromachining and microsystem applications, including industrial material processing, biomedicine, photonics and semiconductors [22].The ultrafast or ultrashort laser means that the laser pulse has a duration that is somewhat less than about 10 picoseconds – usually some fraction of a picosecond (femtosecond) (a picosecond = 1 x 1012 second) [23].It utilizes the ultrashort laser pulse properties to achieve an unprecedented degree of control in sculpting the desired microstructures internal to the materials without collateral damage to the surroundings.It has been proven that microstructuring with femtosecond laser pulses is an excellent tool for free design microfabrication of almost all kinds of materials [24].With the filament, spatial scanning and other methods, many types of optical microstructures (including 3D) such as optical memory, waveguides, gratings, couplers and photonic crystals were produced successfully inside a wide variety of transparent materials of solid state and also liquid state [24].Heating has been widely used for assisting in forming processes, largely due to the improvement of the material followability and reduced strength at elevated temperature.Therefore, the forming processes can be easier and forming loading can be reduced.The influence on the forming tools is a mixture of the reduction of the forming pressures and superimposition of thermal loads from the heating.Introducing heating helps to process materials with higher strength and/or to extend forming ability including component/part forms and dimensions and aspect ratios.Heating with laser is especially effective for the forming of sheet metals or thin sections from bulk materials [25].By selectively applying the laser beam to the focused area(s), the laser can be used in processes such as bending, deep drawing, stamping, can extrusion, tube forming, etc.[21].Transparent tools made of sapphire permit the guidance of the laser radiation directly onto the workpiece within the closed tool set during the process.This means that no separated preheating step is needed and extended processing time is avoided.

Replication Techniques:

Replication techniques like LIGA, microinjection molding, microcasting and microembossing are seen as solutions to low cost, mass production of microcomponents/features, reeltoreel UV embossing being a good example for mass production.Materials that can be processed with replicating techniques include metals, glass, polymers, etc.Especially, embossing, molding and casting are very effective for fabricating microstructures for optical elements/ devices [26], which can produce high resolutions possibly in the nanometer ranges with some processes, and allow the fabrication of large areas and complex microstructures.Processes for gratings, holograms and diffractive foils are well established.Efforts are continually being made to extend the process capability such as increasing the aspect ratios of the microstructures, producing these in larger areas (such as replicating microstructures with optical functions with dimensions between 200 nm and 50 µm on areas of up to half a square meter), combining embossing with other processes such as lithog raphy, dry etching and thinfilm coating, etc.Micropowder injection molding (µPIM) is a potential low cost mass fabrication process for manufacturing microstructures and microcomponents [27].It could be used for processing many different materials (e.g.ceramics and metals) for very complex geometries.For making small geometries, silicon mold inserts may be used, taking advantage of deep reactive ion etching.The processing parameters need to be carefully set in order to produce the required quality and small features.LIGA, an alternative microfabrication process combining deep Xray lithography, platingthroughmask and molding, enables the highly precise manufacture of high aspect ratio microstructures with large structural height ranging from hundreds to thousands of micrometers thickness which are difficult to be achieved with other manufacturing techniques.Significant progress in MEMS manufacturing is largely due to the introduction of the LIGA process.The polymer LIGA process is especially suitable for mass production.There is a chapter in this article specially describing this process.

Deposition Methods:

The methods are seen as effective ones for fabricating multimaterial devices with no need to increase the process chain.Possible methods for Micro-manufacturing include laserassisted chemical vapor deposition (LCVD), laser guided direct write (LGDW) and flowguided direct write (FGDW), shape deposition modeling (SDM), localized electrochemical deposition, etc.[28].For example, a similarity between the siliconbased MEMS methods and shape deposition manufacturing (SDM) is that 'both integrate additive and subtractive processes and use part.And sacrificial materials to obtain functional structures [29], while the latter Is able to deal with more types of the materials.A microrapid prototyping system based on a deposition technique may include microdeposition, ultrasonicbased micropowder feeding, dry powders cladding/sintering, laser micromachining (a laser beam with a wavelength of 355 nm, for example) [29].Fabrication of mesoand microstructured devices by directwrite deposition and laser processing of dry fine powders is also possible [30], which is also seen to be an effective way to fabricate 3D structures with heterogeneous material compositions.The directwrite deposition system is able to produce a 100 µm minimum attainable feature size for device footprints ranging from submillimeter to a few centimeters' on a movable substrate.The prototype devices produced included microbattery, interdigitated capacitor, fractal antenna, Swissroll microcombustor, and functionally graded polymeric bioimplants.By combining an electricchemical method and an etching method, a new manufacturing technique, socalled Efab manufacturing (a system developed by MEMGen, USA), has been developed [31].The method adds layers from 2 to 20 microns thickness and is able to create 3D metallic features with support of the sacrificial material that is etched away late.SDM combining microcasting with other intermediate processing operations (CNC machining and shot peening) was also attempted to create metallic parts [32].The better product quality could be achieved with proper control of interlayer metallurgical bonding (through substrate remelting) and the cooling rates of both the substrate and the deposited material.Another good example of fabricating complex metallic microstructures is to use lithography and etching techniques to make sacrificial silicon molds.The multiple silicon layers are stacked and the metallic glass is then forced into the cavities under heat and pressure in an open air environment.Such an approach could be a solution for low cost manufacturing [33].The inkjet technology offers a prospect for reliable and low cost manufacture of flat panel displays (FPD).Compared to other conventional processes, an inkjet printing method for color filters (C/F) in LCD or RGB patterning in OLED offers potential for the mass production of the enlarged display panels with low costs [34].

Assembly/Packaging:

Basic processes for microassembly and packaging include mechanical placement/insertion/ pressing, microwelding; resistance/laser/vacuum soldering, microcasting/molding, bonding; gluing, etc.Interconnection and packaging solutions (e.g.3D molding of interconnect devices) are the key technologies for connecting microsystems to the macroworld.Molded interconnect devices (MID) technologies include insert molding, one shot molding and two shot molding.Assembly/ packaging gains more importance with the growth of complexity and miniaturization of the products and systems.Although significant progress has been made in the manufacture of individual microcomponents/parts, as well as MEMS, there is still a significant amount of manual work involved in assembly/packaging of microproducts and systems.Assembly of individual technical components to hybrid microsystems is often a bottleneck to largescale production [35], which is evident especially in the areas of heterogeneous assembly, online inspection and quality control.Integration of microand nanodevices through assembly is still a new area of challenge.A method for achieving electrical and mechanical interconnects for use in heterogeneous integration was combining metal reflow and a selfaligned, 3D microassembly [36], which allows for the batch processing of a large number of heterogeneous devices into one system without sacrificing performance.Microassembly injection molding gives another option for joining plastics and some inlay part such as fiber reinforced needle and other elements [37].The use of lasers for welding has exhibited tremendous growth over the last decade for improving efficiency and reducing costs in a broad range of industries for the manufacture of both macroand microcomponents [21, 38].Efforts are continually being made for the better understanding of processes and for controlling key parameters for better quality and efficiency.Online inspection on joint quality is an important issue for industry.For some microdevice assemblies, there was almost no efficient online inspection system available for industry to use, and therefore quality control was extremely difficult.Another key issue for both MEMSand nonMEMSbased manufacturing is the need for effective and efficient gripping techniques/systems and corresponding manipulation strategies/ means for microassembly [39].

VI. Process Chains And Hybrid Processes

Manufacture of a component/product often cannot be completed with a single process: it may involve a process chain.Better quality and efficiency of the manufacture could be achieved with a properly defined process chain.This also applies to Micro-manufacturing which often needs several processes to complete a component.A typical example is combination of plating/coating, chemical etching and stamping to make 3D microsheet components.If microtooling is considered, the process chain is extended even longer.Various process chains are possible in order to meet various design and manufacturing specifications.For example: combining lithographic tooling and significant efforts were made to improve the precision of the machine structures, to compensate for mechanical and thermal errors, as well as to increase the functionality, resolution and reliability of the monitoring systems.The cost paid to achieve these has been very high, while the resulting equipment is too expensive, which actually limits their applications.

Miniature Manufacturing Systems and Benchtop Machines:

During the last 15 years benchtop/desktop machines or miniature manufacturing systems have been gradually developed and introduced to industry.The development of such machines/ systems has attracted a lot of interest from research organizations and industries.A main consideration is that conventional facilities for manufacturing miniature/microproducts are not compatible, in sizes, to the products to be made in miniature/micromanufacturing.Therefore, it is necessary to reduce the scale of the equipment which could, in turn, reduce the energy consumption and material requirements, reduce pollution, create a more userfriendly production environment, reduce equipment cost, etc.At the same.Time, as the scales of the machinery and auxiliary equipment are reduced, the mass of the mechanical parts is reduced dramatically and, as a result, the speed of the manufacturing tools could be increased, which could result in increase in production rates.Another advantageous feature often mentioned is that the force/energy loop and the control loops are significantly shorter for small machinery; therefore, the precision of the machinery could be increased comprehensively.Microfactories are typical examples of such facilities.During the last 15 years several demonstration microfactories (also called miniature manufacturing systems) have been developed [47], notably in Japan, but now also worldwide: a review was provided in the literature [16].These systems and machines indicate a trend of developing the equipment for microand nanomanufacturing.The development of a microfactory itself renders significant challenges to the development of manufacturing facilities, e.g.stringent requirements on machine elements and assembly, as well as monitoring and inspection.In turn, the development of miniature machines or micromachines also promoted the development of a microfactory, which has resulted in various new microfactory concepts.To date, many miniature machines/desktop machines have come to market, such as desktop.Milling machines, EDM machines, injection molding machines, laserprocessing equipment, miniatureforming presses, multiprocess equipment, etc.Compared to the traditional micromachine concepts, currently commercially available desktop machines are relatively larger but closer to industrial application requirements.These may be seen as bridging the gaps between the micromachines and conventional, largescale machines.Led by the Institute of Product Development (IPU) of Denmark, a miniature press and flexible tool system was developed for the forming of microbulk products [18].The press is driven by a linear servo motor and is capable of fast and accurate motion.The tool system enables eight different bulkforming processes to be carried out by changing only small portions of the tool elements.Precision of the tool system is crucial due to narrow tolerances on the dimensions of the microcomponents to be formed, which requires the manufacture of die cavities within the submillimeter range in diameter and within a few microns in geometrical accuracy.A linear motordriven microsheetforming machine system (benchtop machine) was developed at the University of Strathclyde, UK [19], in collaboration with Pascoe Engineering of Scotland, Tekniker of Spain and other EU partners.The machine is capable of a series of microsheetforming processes for forming thin sheetmetal parts with thicknesses below 100 microns.The machine has a capability of up to 8001000 strokes per minute, a force capacity of 5 kN, and machine precision of 25 microns, with modular and flexible setup.The machine is equipped with a newly designed, linearstage driven, high speed feeder which enables feeding accuracy (thin strips) of less than 5 microns.With properly designed pilot pins deployed in microsheet forming, higher positioning accuracy could be achieved.Another novel development was to transport the parts directly out of the tooling system with a novel partcarrying system.The machine is also equipped with a forcedisplacement monitoring system which reads the data directly from the tooling.The Institute of Production (IFP) of the University of Applied Science Cologne, Germany, leads the development of the first generation hydroforming machine for the forming of miniature/ microtubular components [20].Hydroforming processes were employed successfully in industry for mass production predominantly relating to lightweight automotive components.The mass production of such components at present is, however, limited largely to parts with crosssections of above about 20 mm in width.There was a lack of experience in the hydroforming of tubular, miniature/microparts.A machine system has been developed for forming miniature tubes down to 0.8 mm with thicknesses down to 20 microns.The applications of the system will significantly extend Micro-manufacturing capabilities, especially the manufacture of hollow sectioned parts, such as those used in microhousing, fluidic devices, lightweight structures in micromechanical devices, etc., which have not been achieved before.A benchtop, multipleaxis machine tool capable of machining intricate 3D geometries in components with nanoscale tolerances was developed [4849], led by Brunel University and UltraPrecision Motion Ltd of the UK.The associated new series developments include an air bearing slideway and a rotary table with improved damping capacity (patented) and an ultrahighspeed air bearing spindle (Loadpoint Ltd/UltraPrecision Motion Ltd of the UK), a piezodriven fast tool servo system and piezoelectric actuation unit for vibration assisted machining (CEDRAT Technologies SA of France), new microdiamond tools (Contour Fine Tooling Ltd of the UK), a robotic arm unit for microcomponents/tools handling and management (Carinthian Tech Research AG of Austria), and a tool and spindle condition monitoring system (University of Patras of Greece).

Multipleprocess Equipment:

Multipleprocess equipment is an ideal solution to implement various process chains within an integrated platform, which could significantly reduce the number of component handlings.Another resulting benefit is reduction of the possible accumulation of manufacturing errors.The majority of the equipment/devices developed in microfactory or miniature manufacturing systems cannot be classified as multipleprocess equipment/ devices since these are standalone machines which deal with a particular process.The idea of multiple process equipment has received a very positive response in Asia, typical developments in this region including the multifunctional micromachining equipment developed in a Chinese university which is able to perform several micromachining processes on the same machine tool [50] microelectro discharge machining (EDM), microelectrochemical machining (ECM), microultrasonic machining (USM) as well as a combination of these.Using microEDM, microrods with a diameter of less than 5 µm were ground on a block electrode, and microholes and 3D microstructures were obtained.Shaped holes were machined with a combination of microEDM and microUSM.Another similar multifunctional micromachining system was developed in Ibaraki University of Japan, which is capable of micromilling, turning, grinding, buffing, polishing, EDM, ECM, laser machining and combinations of these [51].The applications included the fabrication of microlens molds.A recent development undertaken in National Taiwan University was a multifunction.High precision tabletop CNC machine [52].With this machine, the machining processes such as microhigh speed milling and microEDM (diesinking and wire EDM) can be performed on the same machine without need of unloading, reloading and readjusting the workpiece for the subsequent operations.The system was also equipped with an inprocess workpiece/ features geometrical measurement system.Microelectrodes as small as 8 µm in diameter and diameter/slenderness ratios as high as 100 could be achieved.Similar development is also seen in Singapore [53]a multiprocess miniature machine tool which includes processes such as microEDM, microECM, microturning, drilling, and milling, as well as electrolytic inprocess dressing (ELID), grinding and single point diamond tool cutting.A microfactory as a whole may be seen as a platform that integrates several processes through several micromachines on the same platform [47].Another interesting development which targeted low cost equipment was a fiveaxis milling machine for machining microparts [54].The machine presented was mainly composed of commercially available microstages, an air spindle and PCbased control board.The machine was used for machining microwalls, microcolumns and microblades.Although this development does not involve multiple processes, it explores an interesting concept that targets low cost equipment which may be exploited for the development of multipleprocess equipment.

Supporting Technologies/Devices/ Systems for Micromanufacturing:

Considering handling at the microscale, factors such as gravity cannot be considered as a main force applied to the parts to be handled.Unwanted surface forces such as van der Waals, electrostatic and surface tension forces are dominant at such a scale [55].The pickandplace issue has to be addressed fully, due to the existence of adhesive forces.In microhandling the possible joint backlash and structural vibration due to link flexibility may have to be controlled at the level of several microns during automated positioning.Higher care on manipulation and cleanliness are required also.The problems associated with microhandling may be well understood, but a key challenge is still handling to match the high production rates to be deployed with some miniature/Micro-manufacturing machines such as microstamping machines.This is far more difficult to achieve, compared to that in a slow assembly/packaging process.Sensor systems play an important role in many fields of manufacturing.Their applications in Micro-manufacturing such as that in equipment and that for online inspection require high levels of accuracy/resolution of the sensors.Data processing near the sensors, extracting more information from the directly sensed information by signal analysis, system miniaturization, multisensor uses, etc.are the new demands [56].Singlefunction transducers may now not be sufficient to meet the needs, and the systembased sensors as system components are being introduced: systems containing sensors, actuators and electronics are being developed.Micro-manufacturing technologies are still being developed, and quality assurance plays an even more important role in order to ‘efficiently support the transition of micro production processes from nonrobust to stable processes’ [57].Quality assurance faces particular challenges at the production level some common quality methods for macrolength scale manufacturing may be difficult or even impossible to be applied/implemented.The need for the development of the technologies and systems for dimensional metrology at different length scales and integrating them is evident.As critical dimensions are scaled down and geometrical complexity of the objects increases, the available technologies and systems may not be able to meet current and development needs.New measuring principles.And instrumentation, tolerancing rules and procedures as well as traceability and calibration, etc.will have to be developed’ [58].There are no microspecific tolerance guidelines for general tolerances and these currently largely rely on experience, which is, normally, not statistically established in a factory site and/or has not been approached in a systematic way [59].3D measurement technology that would enable fast, accurate measurement of solid shapes in submicron and even nanometer regions is essential for Micro-manufacturing tasks, e.g.triangulation and optical interferometry may be used in the 3D measurement of the dynamic behavior of the MEMS devices [60].Concerning surface inspection methods and the performance of noncontact profilers, there is no single system which is able to offer all the features that a general purpose user would like simultaneously [61].Providing all possible means available and integrating them into a flexible system to allow users to deal with different inspection requirements may be a solution to meet the manufacturing needs.

VII. Development And Utilization Strategies Of Micro-Manufacturing Technologies

A series of methods and technologies has been developed in the Micro-manufacturing field and the trend will continue.These methods and technologies are, mostly, materials and products oriented.This is particularly the case for manufacturing since many particular considerations need to be taken into account in the manufacture of microproducts, as discussed in previous sections.As far as a method and technology developer is concerned, it is particularly important to understand how the endusers assess the methods and technologies developed, and how a decision is made on the selection and utilization of the manufacturing methods and technologies, even when the product manufacturing requirements are known.Since significant knowledge gaps still exist, especially for those emerging Micro-manufacturing technologies, plus significant lack of standards and manufacturing/ production guidelines, selecting an appropriate technology/process for the manufacture of a particular microproduct may not be a straightforward task.A methodology for the evaluation of the emerging technologies, particularly MEMS technologies, was proposed [62] which involves a ‘triplegateway’ analysis, in terms of considering commercially or socially worthwhile features of the technologies:

1. A market gateway analysis on new uses, user skepticism about ‘improved performance characteristics, requirements for behavior adjustment by the user, competitive technologies, unpredictable technological development and legal barriers.
2. A systemsmanagement gateway analysis on the organizational structures of the company and business.
3. Across the technology/gateway threshold concerning four elements of technology uncertainty: innovativeness of technology, number of constituent technologies, manufacturing difficulties, and institutional changes required to introduce the new technology [62].

In some cases, to have a clear view on the issues such as competitiveness of the technologies and unpredictability of the technological development is not easy to achieve, while the issues relating to possible manufacturing difficulties and institutional change needs are particularly important to an industry.Similarly, lifecycle assessment (LCA) methods may be introduced to the assessment of emerging technologies such as micro/nanomanufacturing technologies, e.g.assessment on the impact on the environment (eco efficiency improvement) which may consider materials, production, uses and disposal, possibly taking future changes into account [7].Other methods for assessing Micro-manufacturing methods and technologies are also possible, each of which may be focused on a particular issue such as scientific and technological issues, collaborative issues, etc.Assessment of the emerging technologies to be utilized with a view to fully understanding the implication and impact on the business is very important.Experience should be learnt from previous cases in the MEMS field which saw that some enterprises were struggling to survive or disappeared from the business.A business built on immature prototype designs and products with low volumes always takes a risk.Micro/nanomanufacturing, at the moment, may still be an expensive business which is characterized by high investment in resources (facilities, knowledge and skills) and often by low volume production and lack of a complete business chain locally.Decision making on the development or utilization of the technologies should take these factors into account, together with other technological issues, such as dealing with multimaterials, small geometries, increased and complex functionalities of products, etc.In particular, the following aspects should be looked I at at stra strategically in relation to the strategies of the development and utilization of Micro-manufacturing methods and technologies.

Manufacturing and Supply Chains:

Development of Micro-manufacturing technologies largely depends on the demands and enthusiasm from industry.The industry's decision is influenced significantly by the perspectives of new business to be brought or improvement which could be made to the existing business.Besides the efforts in developing individual manufacturing technologies, completing manufacturing chains and providing industry with flexibility to optimize the manufacturing chains are also very important.This is not because significant numbers of microparts/components often cannot be produced/completed with single technology alone but also because an optimized manufacturing chain may result in better quality and efficiency.Since no single technology could claim to be dominant, a possible solution to the industrial applications of Micro-manufacturing is to provide various technologies and means for the industry to be able to effectively and efficiently form the required process chain(s), with lower cost.Completing supply chains for micromanufacturingbased business is another important issue to be addressed.Forming effective Micro-manufacturing business chains is often affected by the lack of the required material and high quality tool supply, as well as auxiliary facilities such as that for inspection and testing, although demands on microparts/components is highly evident.Without complete and efficient and manageable supply chains, a sustainable Micro-manufacturing industry cannot be established.Strategic efforts should be made to complete manageable Micro-manufacturing supply chains regionally and/or globally.Advanced methods and systems for supply chain management for the semiconductor industry, and the microelectronics manufacturing industry in general, are mature and have been applied to the industry widely.These have not been developed exclusively for addressing the emerging Micro-manufacturing industry.One of the main challenges also results from the fact that significant numbers of enterprises in Micro-manufacturing are small and only of a short time in business, etc.Development in material and production planning with good knowledge of cost implications is insufficient for emerging micromanufacturing, including lack of the advanced MRP systems exclusively for micromanufacturing.The lack of standards exclusively for microproducts, materials, manufacturing methods and technologies also makes management of the supply chains more difficult.Good strategies are needed for marketing and financing, considering the nature of Micro-manufacturing for a new business.Attention should also be paid to recycling and reusing micromanufactured products and materials.

Integration with Other Manufacturing Activities/Sectors:

A good solution for fostering a Micro-manufacturing industry may be to become associated with some other business or to give support to Micro-manufacturing at an early stage of the development.There are two considerations.First, Micro-manufacturing cannot be an isolated activity and it should be an efficient means for linking macroand nanomanufacturing.There will only be limited impact from nanomanufacturing if it is not effectively integrated with micromanufacturing.It is the same for Micro-manufacturing effectively building microsystems or integrating results from microtechnologies and science, into the macrosystems, will be a key measure to the success of micromanufacturing.Second, development of new Micro-manufacturing business needs strong backing from successful businesses in macromanufacturing, technologically and financially.Currently, significant numbers of business and research activities in Micro-manufacturing are actually transformed from macromanufacturing, which has helped the development of Micro-manufacturing tremendously.More attention should, however, be paid to the issues associated with the microworld for which some methods and technologies cannot be simply scaled down' from the macroworld.

The micro/nanomanufacturing industry may be still small, compared to other industries like transport, space, health, etc.However, it should really play roles in driving other industries to a new level.These may be reflected in the following aspects:

- Traditional industry needs breakthrough/transformation/improvement, considering significant competition and demands on the new products and higher quality.Achieving these cannot rely on organizational measures alone, but also requires, significantly, technological measures.Research and technological development in micro/nanomanufacturing is one of most promising areas that could deliver the required solutions.
- Research in developing new micro/nanomaterials will meet many material challenging issues faced in traditional material and manufacturing industry an area in which, currently, significant competitions exist.
- Manufacturingprocess concepts evolved in micro/nanomanufacturing research will significantly change/update traditional manufacturing concepts in terms of effectiveness and efficiency, these being due to the need for better understanding and control of the manufacturing processes as well as to the new way in which the products

are manufactured in micro/nanomanufacturing.No matter which length scale is to be dealt with, the process development in micro/nanomanufacturing is of general significance to all length scale manufacturing.
- To be able to meet much more stringent requirements in tool fabrication for micro/ nanomanufacturing the process will deliver new knowledge and enabling techniques for the whole tool industry, which will better equip the traditional tool industry for meeting new challenges and competition.Typical examples include tool dimensional precision.And surface quality, tool material performance, etc.
- New manufacturing machine and system concepts, such as benchtop, miniature, micromachines and systems, will have a significant impact on all manufacturing sectors in design, fabrication and use of the machines, in relation to performance, impact on users and environment, energysaving, etc.
- Micro/nanotechnology products designed and/ or prototyped in other sectors may have to be brought to market in order to have real impact/ economical gains – micro/nanomanufacturing is a sector that can make it happen.

Technological Performance/Maturity Level:

Compared to macromanufacturing, one of the difficulties in assessing the technological performance/competitiveness of a Micro-manufacturing process and the equipment lies in the significant number of existing uncertainties.Capabilities on material, geometry, tolerance, production rate, ease to link with other processes and equipment, etc., are often difficult to be defined in general terms, as these are often affected by many factors as described respectively in several sections of this chapter.The strong material, dimensions and environment dependence in micromanufacturing, including the skills of the workers, make comparison of different processes and equipment very difficult to achieve.Nevertheless, the following aspects should be examined in terms of assessing the technological performance and maturity level Micro-manufacturing process and equipment:
- Geometry associated performance: achievable overall dimensions, feature geometry, tolerances, surface finish, possibility for length scale integration manufacturing, etc.
- Material associated performance: type of materials processable, material property requirements/constraints (e.g.microstructures and surface integrity), postprocessing requirements, etc.
- Production associated performance: yield, reliability, scalability, online/inprocess monitoring/inspection ability, ease for integration into process chains, dependence on skills/environment, impact on the environment, etc.
- Cost factors: all costing items including that for auxiliary processes and equipment (e.g.that for handling, assembly/packaging, cleaning, etc.)

Other Issues:

Besides a series of activities such as economic analysis, decision analysis, technological forecasting, information monitoring, risk assessment, market analysis, externalities/impact analysis, etc., education and training are important for the Micro-manufacturing industry.These are needed due largely to Micro-manufacturing being generally a knowledgeintensive business.

VIII. Conclusion

Micro manufacturing is a rapidly evolving field that offers immense potential for the development of novel devices and components.However, it also presents unique challenges that require a deep understanding of the underlying theory and principles.By addressing these challenges and advancing the theory of micro manufacturing, we can unlock new possibilities for miniaturized technologies across a wide range of industries.microelectronics theory plays a central role in the development of electronic devices and systems that have revolutionized the way we live, work, and communicate.By advancing our understanding of semiconductor physics, fabrication techniques, and device design principles, microelectronics theory continues to drive innovation and shape the future of technology.

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