BUSINESS AND TECHNOLOGY CHALLENGES IN ELECTRONICS INDUSTRY IN THE EARLY 21st CENTURY

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Abstract: The end of the 20th century has been characterized by a rapid technological evolution and very promising consumption behaviour and a continuous growth seemed to be granted. In 2001 almost all electronics sectors have been severely affected by the implosion of communications market and consequently the biggest downturn in the history of electronics industry.

Despite this recent recession, the progress will certainly continue in the future and the coming years will be the years of extraordinary development of personal, data and wireless communications requiring hand-held, nomadic products and asking for more complex and intelligent integrated circuits. It will require a very strong miniaturisation, an increase of working frequency and a significant cost reduction. High performance, high volume, low cost and a very short time-to-market are the main drivers.

Poslovni in tehnološki izzivi v elektronski industriji v zgodnjem 21. stoletju

Ključne besede: tehnološka revolucija, poslovni trendi v elektronski industriji, tehnološki izzivi v elektronski industriji, tok podatkov, komunikacije

Izvleček: Konec 20.stoletja sta zaznamovala hiter tehnološki razvoj in povečanje potrošnje, kar naj bi zagotavljalo stalno rast ekonomije. Toda v letu 2001 je vsa področja elektronike prizadel razpad trga telekomunikacij, kar je imelo za posledico največji poslovni padec v zgodovini elektronske industrije.

Navkljub tej zadnji recesiji, se bo napredek v prihodnjosti nadaljeval. Sledila bodo leta izjemnega razvoja na področju osebnih, podatkovnih in brezžičnih komunikacij, ki bodo zahtevale prenosne in gibljive naprave ter posledično povzročile povpraševanje po bolj zapletenih in pametnih integriranih vezjih. Razvoj bo zahteval agresivno miniaturizacijo, povečanje delovnih frekvenc in zmanjšanje stroškov. Glavne gonilne sile tega razvoja bodo tako zmogljivi izdelki, kratki časi razvoja, nizki stroški in velike količine.

1. INTRODUCTION

The progress and changes in electronics and microelectronics industry are extraordinary. Just over 120 years ago Thomas Edison realised the first lamp and today's portable computer is making thousands of millions of operations per second and there isn't almost any human activity where electronic would not be present. The complexity of integrated circuits and their performance is doubled every 18 months following thus the famous Moore's Law. This enables to integrate a several millions of transistors in one chip, making circuits more and more complex and intelligent. There is no doubt that technical progress will continue but after the disastrous downturn in 2001 the economy changed and in the future only the most dynamic, the most flexible or the most diversified companies able to continue to develop new technologies on the economical basis and to serve different markets will survive. How it will influence the future trends?

2. BUSINESS AND TECHNOLOGY TRENDS IN ELECTRONICS

2.1. General trends

The coming years we will see the development of personal, data and wireless communications requiring hand-held, nomadic products for consumer electronics but traditional market sectors such as military, instrumentation, avionics, medical which were in the past driving forces for performances, will be still valuable and granting the business stability. High performance, high volume, low cost and a very short time-to-market will be the main drivers.

As we are just at the beginning of the 21st century we will try to find out what are the business, technology and economic challenges in face of electronics companies in the coming years.

Technology - The most visible and obvious change in the electronics industry has been in technology. The driving force will be the application of the mix of analog, digital and embedded software technology to ever-increasing applications. To reduce operating complexity and cost, we are seeing new products i.e. System-on-Chip (SOC) dedicated to specific functions. Many of these dedicated products will be built from reusable and/or programmable cores. System designers will select the functions they need and "turn off" those they don't. A model for success into the next millennium, the Silicon System Platform (SSP) goes beyond today's SOC and is based on software and hardware re-use. It defines a flexible way to build sophisticated systems from a small number of blocks, all of which may be different but which can be put together following common rules. Today's technology is limited by the number of functions we can put on a chip and the speed we can make electrons move. Researchers are looking at optical, chemical and biological structures, but none of these are far enough along to be a practical replacement for electronics.

Processing & packaging - Integration and miniaturisation of electronics became a challenge. Changes in packaging have been both: internal (building and interconnecting transistors on the chip) and external (interconnecting of chips inside a multichips module and interfacing to the board). New processing and packaging technology also offer a lower cost.

Design & production processes - The design process of advanced mixed-signal IC is very complex. As a direct consequence of this, the design of digital products and equipment now requires several design groups working in parallel and much of the analysis-intensive process has been automated on computers. Before the digital revolution and Electronics Design Automation (EDA), electronic systems were designed by trial-and-error and test instrumentation was a key component in the design process. Today exist powerful EDA's tools for high level synthesis and simulation enabling the design of multimillion gates digital ICs.

On the other hand, the complexity of analog or mixed-signal parts design is still a barrier to a real synthesis technology. When considering the future of synthesis in the analog/mixed-signal world, one must consider the limitations that intellectual property libraries and the designers' behaviour impose. Other factors driving design process change were integration and miniaturisation. When prototype test was key to the design project, we planned for three or more prototypes to get it right. Now, most testing is done on computerised model in a design automation system. The ideal is a prototypeless design that works the first time and the collaborative development or concurrent engineering is taking more and more importance in design cycle.

With ever increasing IC complexity and feature size reduction the cost of design and production of highly-customized made-to-order products become incompatible to the manufactured volume per specification. A cooperative R&D is a part of a global solution for cost sharing.

Technical knowledge & intellectual property - The key questions today are no longer "What new technologies can we develop?" and "What can we use this technology for?" but "What technologies do we need to serve this market?". Customer knowledge, rather than leading-edge technical knowledge, has become the key source of new product innovation.

Semiconductor makers are starting to question the value of their production divisions. They cannot overwhelm the competition with their own in-house technology alone. Companies can get an edge by having the world's best technology in one area, and using the industry standard or acquired technology elsewhere.

Industry structure - Also the industry structure is changing from a vertical integration around industry segments to a new horizontal structure based on four major levels of integration (packaging): chip-level integration (ICs), board-level miniaturisation (SMT), productisation (PCs, peripherals, communication sets & instruments) and system integration. These four levels require distinctly different design, manufacturing and management skills and techniques.

One big change is in supply chain management. Rather than a simple, sequential structure of a chain, modern demand and supply networks require real-time, continuous interaction with parallel co-ordination among multiple business partners. While technology forecasters do not make long term projections, they estimate by 2004 as much as 40% of all electronics manufacturing outsourced.

E-commerce is a direct result of the need for companies to reduce the cost and cycle time associated with procurement programs. Electronic transmission of purchase orders, requests for quotations, order confirmations, demand forecasts and electronic payments, save companies time and money.

2.2. Industry strategy after 2001

The computer, communications and consumer electronics industries are merging and it is no longer possible to tell the difference between them until after they have been configured for specific applications. Also many of these products are being adapted for industrial or military uses. Making predictions in a rapidly evolving industry is a tricky business, but some CEOs agree that across high tech, survival over the next five years rests on management's ability to be more flexible than ever in how they seize opportunities, more creative in finding the competitive strategy hidden in their supply chain, and willing to invest more heavily in learning about their customers and what they want /1/.

The downturn in 2001 has affected everybody, but there were companies that managed quite well and not only survived the slowdown but even enlarged their market share. Looking to the strategy of these "winners" one can observe that they all maintained a diverse group of products in different market sectors and different geographical areas and they continued investing in research and development.

The long-term winners should have a flexible cost structures, a flexible portfolio approach being able to accelerate, hold, or kill the development projects as appropriate for the current market conditions, a portfolio that will be well targeted, cohesive and competitive. They will develop a true gain-sharing partnership with their suppliers and a honest relationship with staff and sell products through the optimum mix of direct and indirect sales channels.

2.3. Market segments and evolution

Communications - Communication and computing have now converged in an exceptional development. New ideas for the future communications appear. *Alcatel* on *ISS European 2002* conference in Lisbon, presented its strategy set to match the needs of what the company identified as the "Ambient Intelligence" of "Sentient Spaces". The idea is that communication devices could deploy a digital environment that is sensitive, adaptive and responsive to presence of people. By processing the context of gathered information, services could be triggered by the computing devices present within the user's environment /9/.

Until 2000 the GSM was the biggest driver of the wireless market in the world. After the unforeseen downturn in 2001, market specialists are cautious. However they predict about 1 billion units in 2004 and 1.2 B in 2006 (about 33% in Europe). The arrival of new technologies for mobile Internet such as 3G, I-mode, UMTS or GPRS should have a limited growth at that time and shouldn't affect too much the above figures.

The 2.4 GHz wireless communication protocol "Bluetooth" arrives much slower than foreseen. The "Bluetooth" standard defines a short-range radio link capable of voice or data transmission in the unlicensed ISM band at 2.4 to 2.48 GHz using a spread-spectrum, frequency-hopping, full-duplex signal. Modules are assembled today as MCM on LTCC substrates, waiting for single-chip solutions. The "Bluetooth" market is expected to grow from 70 M units in 2002 to 700 M in 2005 according to the figures announced on *Bluetooth Congress 2001* in Monaco. Also the offers are diversified and other standards for wireless communications appeared (HomeRF, 802.11x, HyperLAN).

The well-known SMS (Small Messaging Services) sending today only a text massage will be replaced in the future by MMS (Multimedia Messaging Services) able to provide text, image, audio and video.

The third-generation UMTS (Universal Mobile Telecommunications System) mobile handsets will carry voice, data and video for mobile multimedia and will be 10 times more complex than today, however its introduction been delayed by many telecom operators from 1 to 3 years! First terminals for the "3G" were presented in February 2002 on the GSM Congress in Cannes, France. Presented there, *Motorola*'s A820 mobile includes all multimedia MMS functions (voice, video, images), MP3, GPS and even video camera. Despite the development of new technologies some specialists predict that the global revenue from worldwide telecommunications including base stations, mobile phone, fix phone and networks, and local area networks will not recover the downturn in sales revenue before 2004.

Networks, Internet - *Dataquest* projects the market for data-networking equipment will grow from $ 160 billion in 99 to $ 216 billion by 2003. The GSM's infrastructure is still the biggest market (49% of cellular phones) however new systems progress rapidly. The investments in 2001/2002 for the networks of "3G" represented 35% /2/. According to *IFX Market Model* the wireless modems should grow from 200 M in 2001 to about 1 B units in 2005. These figures include WLAN, Bluetooth, analog and digital telephony.

The physical transport of the data streams has typically been done over microwave links, coaxial cables and optical fibers. But as data rates increase, copper and microwave based schemes rapidly run out of bandwidth and give way to optical fibers. Holding a lot of promise for the future, Wavelength Division Multiplexing (WDM) and its recent generations promise ten- to thousand-fold increase in data throughput.

Asymetric Digital Subscriber Line (ADSL) transmission technique, revealed in 1994, multiplies by hundred telephony lines capacity contributing to the development of Internet video transmission.

Information appliances, Multimedia, Entertainment - Networking, multimedia and portability are giving people the ability to move around with the constraints of time and location by letting them communicate anytime, anywhere and with anyone. These "nomadic" products include cellular phones, personal digital assistants (PDA), hand-held PCs and intelligent cards. Collectively called "digital consumer products" (DCP) they will become major segments of the semiconductor market in the new century. Powerful information appliances will include telephones that provide voice mail, e-mail and faxes on one screen, voice-controlled set-top boxes that capture and play videos and DVDs, enable e-commerce and bring together the power of voice and video communications, freestanding, PC-independent smart printers and Web-connected kitchen appliances.

Automotive, Telematics - The part of electronics in car is continuously growing. Engine management, security, navigation, telematics are the most important applications.

The future car will be able to give directions (navigation, parking assistance), to perform diagnostics, to tune equipments automatically (seat, radio, engine, road-handling management), to keep its owner safe (airbags, emergency call system, ABS, collision and blind-spot detection, remote keyless entry) and to communicate via wireless, Internet, FM/digital radio broadcast and vehicle-to-roadside. The electronics entered to the engine and control it precisely by means of piezo-ceramic injection system. The lighting benefits from High Density Discharge xenon lamps and a rapid progress in DEL luminosity.

The number of sensors in car explodes: a high end cars can have as many as 60 sensors. In order to facilitate the management of all these systems *SAE* (*Society of Automotive Engineers*) defined three classes of communication networks. Class A for communication at low speed (<10kbit/s) for comfort applications (audio, air conditioning, doors locking), class B for medium speed (10 to 125 kbit/s) for general information transport (instrumentation, speed control) and class C for high speed communication (125 kbit/s to 1 Mbit/s) for all real-time applications (engine control, breaking, airbag triggering). Every class has its own protocol of data transfer.

The introduction of 42V power supply network will require many new power electronic components and actuators as well as new batteries system.

Telematics is an emerging market of automotive communications technology that combines GPS, cellular phone, modem and software to provide location-specific security, information, productivity (news, multimedia, Email) and in-vehicle entertainment services for drivers and passengers (movies, DVD). And, from the automobile, navigation systems will communicate with local traffic-monitoring networks to provide the best route home for avoiding rush-hour traffic.

Domotics and Personal Applications - The first products compatible with HomeRF standard arrive. They use the band of 2.4-2.5 GHz and enable a transfer speed of 2 Mbits/s and plans are afoot to raise to over 10 Mbits/s. The specification is designed to simplify communications between PCs, peripherals, cordless phones and consumer electronic products in the same house. The domotics applications will grow considerably in coming years and will become one of the largest market sectors.

Today's electronics is generally integrated into a package. The future electronics will be also embedded into personal care objects such as clothes, glasses, belts, bracelets. That's a new emerging domain called "wearable computing" or "communicative wear".

Medical - Beside the traditional applications such as pacemakers, blood pressure measurement, insulin injection or hearing aids the electronics is more and more used in other domains. To visit intestines, there are now available special highly miniaturized pills equipped with CCD camera and DEL day- or infra-red lighting, able to transmit 30 images per second video, takes samples or inject a medicament.

The brand new application is brain stimulator to help in case of Parkinson disease.

Today's chemistry allows to elaborate polymers macromolecules which change their shape under the action of an external stimulus (electrical field, light) and can act as actuators. Thus new application domains appear: bio-medical and micro-surgery (prosthesis), space (robots), micromechanics (clock industry, micro-robots) and nano-technologies (sensors-actuators).

Looking more ahead we can imagine that in 10 or 20 years paralysed will walk grace of electronic robotized prosthesis, blind will see thanks to video camera connected directly to the view nerve and even a memorisation process could be aided by an extended memory.

Smart-Cards - For the first 20 years of its existence, the smart-card market has been dominated by single-application cards such as phone-cards, bank cards, pay-TV cards, GSM SIM cards, health cards and many others. The key challenge faced by smart-card chip manufacturers was to provide the highest level of security appropriate to the application at the lowest possible cost.

The smart-card of the future will support multiple applications, many of which will be downloaded after the card is issued. In this way, a single card will be able to act as a public transport payment card, a phone card and so on with the ability to link these functions securely. Interoperability, complying with international standards, will be a key requirement, in addition to the perennial cost and security issue.

Contactless operation will also play a rapidly growing role in the smart-card market. RFID etiquette is an emerging market but with a huge potential. Personal, vehicles, products on shelf contactless identification is estimated to progress of 35% a year to reach $ 7.5 billion in 2006. As per today RFID can communicate via GSM mobile phone. The major obstacle today is a lack of common standards.

The brand new application, related to the security, is a card using bio-metrics principles for persons identification. They use silicon, capacitive passive, active or reflective sensors for face and fingerprint recognition basing on ultrasonics or optical principle.

2.4. Electronics technology evolution

Semiconductors - 2000 and 2001 have been two record-setting years for the electronics industry. In 2000 production and sales of electronic equipment both reached their highest historical level and set a 20-year record in growth. 2001 will have known the first recorded downturn in the 50-year history of electronics industry. According to preliminary statistics by *Gartner Dataquest* the global semiconductor market revenue declined by 33% to $ 152 billion /3/.

According to the last issue of "*International Technology Roadmap for Semiconductors*" released by *SIA* in 2001, the minimum dimensions should be about 90 nm in 2004, 65 nm in 2007 and 45 nm in 2010. In 2014 microprocessors should use 0.02 μm lines which is considered by *SIA* as CMOS technology limit. Regarding the gate's width of MOS transistors it will achieve 25 nm in 2007 and 9 nm in 2016 which will the physical limit (not enough of molecules to form a layer). Afterwards, something else should be invented.

By the end of 2001, *Intel Corp.* announced the TeraHertz® technology based on depleted SOI substrate, high dielectric constant gate and gate width of 15 nm. This technology enables to build transistor with 2 630 GHz switching frequency ! It should be used for next generation of microprocessors from 2005 onwards. Other big companies also presented transistors with similar performances. They used new materials such as hafnium or zirconium oxide (HfO_2, ZrO_2) to replace traditional SiO_2 /5/.

Recently *IBM* announced the world's fastest semiconductor circuit, built using IBM's latest silicon germanium (SiGe) technology and operating at speeds of over 110 GHz /4/.

Forecasted by *SIA* in 1999 the density of integration should double every 2 years from 2 M transistors per cm2 in 2000 to 44 M in 2005 and 684 M in 2014 for low cost consumer ICs and for high performance ICs from 24 M transistors this year to over 2 G in 2014. In comparison with the above forecast, the last version of *Intel's Pentium 4* microprocessor built with 130 nm lines on 300 mm wafer contains 55 million of transistors and working frequency of 2.4 GHz. In August 13th, 2002, *Intel Corp.* has unveiled several technology developments that it has integrated into its new 90nm process /10/. This new 90 nm process combines higher-performance, lower-power transistors, strained silicon, high-speed copper interconnects and a new low-*k* dielectric material. All of these technologies will be integrated into a single manufacturing process next year using 300 mm wafers.

Advanced transistors: *Intel's* new 90 nm process will feature transistors measuring only 50 nm in length (gate length), which will be the smallest, highest performing CMOS transistors in production. These transistors feature gate oxides that are only five atomic layers thick (1.2 nm). A thin gate oxide increases transistor speed.

Strained silicon: Intel has integrated its own implementation of high-performance strained silicon into this process. By using strained silicon, current flows more smoothly, increasing the speed of the transistors.

Copper interconnects with new Low-k dielectric: The process also integrates a new carbon-doped oxide dielectric material that increases signal speed inside the chip and reduces chip power consumption. This dielectric is implemented in a simple, two-layer stack design, which is easy to manufacture.

The technology evolution prediction, even for near future, is difficult and not always true, as it has been already observed in the past. So it should be taken with reserve. In 2000 the *SIA* forecasted DRAMs 1 Gbit in 2005 and 16 Gbit by 2011. Today these figures seem to be too pessimistic. During the *ISSCC* conference in San Francisco, in February 2002, *Samsung* and *Toshiba* presented 1 Gbits NAND flash memory and recently *AMD* announced a memory based on MirrorBit technology enabling to stock 2 bits per gate. In February, *Intel* used its 90 nm process to make the world's highest capacity SRAM chips at 52 megabits. These fully functional chips pack 330 million transistors in an area measuring only 109 square millimeters.

As existing storage principle are not completely satisfactory, new principles of an "ideal" memory are being developed. Although the way of FRAM (Ferroelectric RAM), MRAM (Magnetic RAM) and OUM (Ovonic Unified Memory using the change from amorphe to crystal structure) is still long, they are indicated as the future replacement for existing technologies.

Another solution is to build 3D structures. The good example could be a 512 Mbits memory from *Matrix Semiconductor*, designed with 130 nm rules and 8 levels of stacked cells, takes 8 times less silicon and costs 10 times less than standard memory /6/.

To be able to design and to manufacturers these devices new materials, new lithography methods and new design tools are necessary.

What kind of materials will be used in coming years? For sure in the next 10 years the silicon will be still the basic material with Silicon-On-Insulator (SOI) however SiGe will grow also rapidly as a competitor to GaAs. Also the carbon doped SiGe (SiGe:C) has been qualified en BiCmos process at *Motorola*. According to the "10 top" semiconductor manufacturers by 2005 between 35 to 50% of wafers will be in SOI technology.

The recent progress in silicon reactivated the development of GaAs technology which should allow to reach 400 GHz transition frequency. According to *Strategy Analytics* GaAs will be the first technology used for MMICs by 2003. Especially when GaAs can be deposited on silicon. This technology, developed by *Motorola*, is not only cheaper than standard GaAs, but also enables to integrate on the same silicon chip RF and electro-optics components (laser, LED) as well as silicon IC. Other emerging material such as GaAlAs, GaInAs, GaN, SiC as well as copper in place of aluminium will unavoidably contribute to higher speed and better power dissipation.

The biggest semiconductor manufacturers are working very hard to develop new technologies which will boost electronics industry. *IBM* announced a "strained silicon" technology which improve electrons mobility by 70% and increase transistors speed by 35% without changing its geometry. Next improvement can come from research work in the domain of molecular electronic, especially in field of carbon nano-tubes. Recently *CEA* in France has demonstrated the first quantum transistors called *Quantronium* using aluminium supraconductor and Josephson junction effect.

These always ever higher density components need much improved photolithography technique. The decrease of light length improved continuously was not enough for the future generation of semiconductors. The new Extreme UV Lithography (EUVL) with 13.4 nm wave length and also Electron Projection Lithography (EPL) technology open the doors for 32-45 nm generations.

Another problem is related to EDA tools especially when very fine line rules or mixed-signal design are necessary. It seems that semiconductor industry is going ahead faster than electronic design tools.

As gates density and working frequency increase, also power dissipation became a challenge. A power density in the next generations of microprocessor can rise up to 3 W/mm^2 in hot points. This will require not only packages with a very low thermal resistance but also a power dissipation to the environment (air or board). Very promising solution could be "heat pipelines" integrated to the metallic base of packaging or mother board. Based on the principle of evaporation and condensation, the liquid inside the pipeline (only 125 μm thick) is distributed by the capillarity effect. Thus, *Novel Concept*, an American company, achieved the thermal resistance in the range of 0.09 to 0.28 °C/W for 71 mm square, 1 mm thick, molybdenum heat-sink. *Dynex Semiconductor* has presented a new solution with a "metallic foam" heatsink.

In next 5 years the majority of designs will be done on programmable logic making thus development faster and enabling the reuse of IC-s. By the end of 2001, *QuickLogic* introduced a programmable circuit which contains a full RISC 32bits processor, FPGA, SRAM and ALU blocs, everything fully programmable by the user.

MEMS-s represent a new very fast growing market. They cover many different applications in automotive (air-bag accelerometer, tyre pressure system, ride stabilization), medical (blood pressure monitoring, Lab-on-Chip, insulin pump), environmental (gas sensor) and RF communications sector, where they can be used in tuneable lasers and filters, attenuators, variable optical equalisers, switches, relays, capacitors and inductors. Their attraction reside in their compactness, robustness and their relatively low cost. *In-Stat* projects an optical networking market for MEMS growing from $ 67 million in 2001 to $ 2.3 billion in 2005 /7/.

Because of the basic similarities between MEMS and IC fabrication, several semiconductor companies and equipment providers have moved into the MEMS arena. While the industry is optimistic about the enormous market potential of MEMS devices and applications, there are several hurdles to be overcome before the dream of large-scale commercialization is realized. Some of the teething problems in MEMS fabrication can be categorized as follows:

- Product-specific process: an important requirement for large-scale manufacturing of MEMS devices is the standardization of fabrication process technologies.
- Special raw material: MEMS devices require exotic materials such as gold, piezoelectrics, and shape memory alloys making the fabrication more expensive.
- Low volume, high cost due to the specialized nature of the devices
- Packaging: the diversity of MEMS devices makes packaging an expensive and time-consuming task in the overall MEMS product development cycle

RF&Hyper exhibition in Paris in March 2002, confirmed the fact that the miniaturisation of RF and microwave components is the major factor in this sector. The smallest full "Bluetooth" module in LTCC technology with buried passive components including pass-band filter which needs only an external antenna has been presented. Regarding multiplexing, although the first sets of multiplexer-demultiplexer OC768 at 40 Gbits/s in technology CMOS 130 nm or InP arrived, it seems that for the next 2-3 years circuits OC192 (10 Gbits/s) in technology CMOS will take the major part of this market.

And what about the power management? In 1999, more than 50% of the world's electricity was consumed by electric motors. The majority of them still use an electro-mechanical contactor to turn the motor on or off. Replacing contactors with electronic variable speed motor drives will result in annual savings of up to $ 72 billion in electricity consumption.

Power MOS transistors and IGBT are in fierce competition. They continue to decrease the R_{ON} resistance and increase switching frequency. There is an increasing demand for low profile, high density, board-mounted DC/DC converters.

Also new materials such as SiC and having much better thermal conductivity than silicon have been announced.

Also the bio-chips market interests a lot semiconductor industry. It can offer a low cost solutions for medical diagnostics, for food and for environmental applications. Two types of chips are in development. Simple ones, with biochemical (generally DNA) molecules on glass or plastic substrate and Laboratory-on-Chip (LOC) containing microsensors, micro recipients for tested products, actuators and controlling microprocessor.

Optoelectronic components & displays - The integration of different optical functions on unique platform or better on one chip is the "leitmotiv" of all manufacturers in order to reduce the size and cost of optical components. Technologies of semiconductors III-V, GaAs, InP are currently used. However, 2D MEMS and new principles in switching such as LCD are being developed.

For the last ten years a big development effort has been accomplished in LED field. White and blue LED are the reality and performances of LED surpass now those of halogen lamps. They achieve 40 lm/W level. However, the cost per lumen is still relatively high and especially for white LED. The technology is changing as well. Instead of saphire or SiC as a base substrate, silicon with a thin GaN layer can be used.

Very promising is the use of laser beam for mass storage of data. There are a few major solutions. One of them consists to use a blue laser 405 nm and the density of a standard DVD can be as high as 27 Gbytes. The use of the principle of fluorescence - Fluorescent Multilayer Disc (FMD) allows to stack about 100 layers and to reach to volume of 100 Gbytes per 12 cm disk. Going further in this direction, *Storex Technologies* uses a bloc of FPV (Fluorescent Photosensitive Vitroceramic) with a possibility to distinguish about 1000 levels and to stock 10 Tbytes of data !

The another way is a holographic storage. Many companies (*IBM, NEC, MIT, Bell Labs*) are working hard on this subject. A potential capacity is very high - many Tbytes and transfer speed is about 1000 times higher than presently existing due to the lack of inertia of laser beam. The first, commercially available in 2003 holographic 12-cm disk should have a capacity of 100 Gbytes and a transfer rate of 20 Mbytes/s.

A very rapid evolution is observed also in displays domain. The 3rd generation mobile phones will be equipped with colour displays. Many new technologies are emerging such as plastic LCDs or organic electroluminescent displays (OLED). The major problem is the lifetime, shorter than for other types of displays but the advantage of OLED is that the architecture is simple, there is no need neither for backlighting, nor for diffuser, nor for polarizer nor for filters. It means OLED should be cheaper.

Conversion of solar energy is an other item. The recent development confirms that solar cells can be built using a polymer optimised with nano-composites (CdS nano-tubes) in very efficient and low cost way as plastics are. That has been demonstrated by a Californian start-up *Nanosys*.

MCM, hybrids, "3D" modules - *BPA* makes distinction between performance and simple MCMs. The "simple" MCMs are meant more for the consumer sector and "friendly" environment, whereas the "performance" MCMs belong to the automotive and industrial sector.

The evolution of the first group is stimulated by an explosion of cellular market. The enlargement of the use of LTCC technology with burried components (resistors, capacitors, inductors, filters) contributes significantly to the speed-up of simple MCMs. LTTC technology is used largely for "Bluetooth" and other RF modules.

Also the use of silicon as MCM's substrate jointly with flip-chips, CDAs or CSPs enters in its maturity phase achieving high volume and low cost.

But the major breakthrough comes from integration of IC chips into so called "3D" modules, using either packaged devices (eg. memories in TSOP package) or naked dies. This System-in-Package (SIP) concept is known to combine highest functional density with minimal outline size, minimal Cost-of-Ownership and minimal Time-to-Market even in moderate volumes when compared to Chip-on-Silicon ASICs on one hand or photovia board level miniaturisation on the other.

The ever existing tendency is to pack more and more in smaller and thinner package. Therefore a "thinning" of naked dies down to 100 μm or less is now under development. The specialists project that in the next ten years the thickness of chips in 3D modules will drop to 20-25 μm enabling to integrate in a smart-card a multilevel chip. Its is obvious that traditional wire-bonding technology will be replaced some kind of micro-balls or flip-chip technique.

Passive components - Ceramic and tantalum capacitors stayed for a long time with limited CV values. Today, there is a big move in this sector. Some companies announced already ceramic capacitors X5R (-55 to +85°C) up to 1 μF in 0402 and up to 100 μF in 1210 package. Increasing capacitance and competitive prices are helping multilayer ceramic capacitors (MLCC) displace tantalum capacitors from areas they have long dominated. Both technologies now compete between 0.1 and 100 μF.

For tantalum capacitors, pulled by automotive under hood application, the change occur in CV increase and operation temperature rise. Capacitors up to 100 μF in 2220 and 10 μF 6.3V in 0603 and 0402 are now and also a 150°C and 175°C operating temperature tantalum will be shortly available. On the other hand the aluminium-polymer capacitors with high capacitance and low resistance (2 mW) attack also tantalum ones.

Chip resistors are achieving their size limit of 0201. Further miniaturisation will not improve board space saving due to the necessary solder pads area and placement accuracy. The integrated resistors network will be preferable.

Other components such as VCOs, TCXOs and even OCXOs follow this tendency and their dimensions have been reduced dramatically during the last 2 to 3 years. The physical volume of VCOs has been divided almost by 10 during last three years from 0.2 cm^3 down to 0.025 cm^3. Some of TCXOs come today in 0805 equivalent size and a crystal oscillator of 0.5 mm thick for contactless smart-cards was presented.

Although passive components changed dramatically their size during last ten years, their miniaturization tends to reach its limits. This not even related to size's limitation itself but due to problems with placement's precision, attachment's difficulties and due to the economical reasons. Further miniaturization (except very specific applications) cannot justify the cost of procurement, storage and placement of single chips.

This ever smaller components with ever smaller pitch size require denser mother boards and especially much more precise pick-and-place equipment. Today's equipments guarantee 3 sigma precision of 15 to 25 μm. The specialists say that by 2008 this precision should be improved to 6 to 10 μm in order to be able to mount any kind of components. However, to be able to assembly flip-chip with 30 μm pitch also solder should be replaced by anisotropic adhesive, which present another challenge !.

But as the ratio of passive to active components is more than 20:1 for cell phones, the major breakthrough will come from integration of passive components in a network. The high integration of passive components in one ASPIC results not only in size, volume and height reduction but also in placement cost decrease and yield improvement.

LTCC technology allows the use of dielectric with different dielectric constants, printed coil with reasonable Q factor and antennas.

In RF range, the integration of passive components in a network on silicon above the IC covered with a passive layer of low dielectric constant, could be an interesting solution.

Interconnections - The high density, high speed semiconductors require also much better interconnection and more miniaturised passive components.

Between 1997 and 2002 worldwide market for board-to-board connectors with a pitch of 1.27 mm and smaller (1, 0.8 and 0.5 mm) increased significantly. But the miniaturisation is not the sole parameter. The "high speed" aspect is important as well. The importance of connectors able to guarantee signals integrity at 200 and 500 MHz became more significant. As a traditional connector male-female is achieving its limit with 0.8 mm pitch, connectors based on BGA approach with 0.4 mm pitch arrived.

For fiber-optics a new generation of parallel connectors with a bandwidth of 2.5 to 3.3 Gbit/s per channel have been introduced.

PCB substrates - According to the specialists in this domain the substrates for mobile phone by 2004 will have up to three levels of micro-vias per side with conductor/space 50 μm, micro-vias of 23-30 μm and halogen-free materials. Already some PCB manufacturers announce today technologies with 20 μm tracks width realised in only 5 production steps. This will require heavy investment, investment compatible only with a large volume of production.

We observe a strong development of new materials. Suppliers offer today PCB substrates for almost any application (high temperature, RF, laser drilling) using also other resins than epoxy (polyimide, BT, PTFE). Also bromine-free laminated substrates are improved and qualified. For RF applications above 20 GHz PTFE resin is unavoidable, but its price varies from 6 (low cost version) to 40 times (high performances version) of FR4 substrate.

A brand new idea was to integrate in PCB also optical fibers. This idea came from *IZM Fraunhofer Institut* in Berlin. The optical path realised with a polymer are organised in layers barried in-between electrical signal layers. This OECB (Opto-Electrical Circuit Board) with VCSEL diodes used as transmitters showed during the feasibility phase a transfer rate of 2.5 GHz with insertion losses of 0.2-0.3 dB/cm.

Packaging - Traditional packages, such as SO, TSOP, QFP and PGA show limitations regarding number of pins, packaging density and cost. Emerging packaging technologies like BGA, CSP, SIP (System-in-Package) will be expanded rapidly in coming years. They are in competition with unpackaged solutions (DCA, flip-chip). Wafer-level packaging (WLP), signals special editorial merit with its technological challenges, significant commercial advantage and further integration with "front-end" wafer process.

The role of a packaging is four-folded: to connect the chip to the outside, to distribute signals, to evacuate power dissipation and to protect the chip from the environment.

The increased speed requires lower dielectric constant and lower losses in substrate. Therefore there is a tendency to move from ceramic to new organic substrates. Higher frequency contributes to higher power dissipation which not only demands better thermal conductivity of packaging but also the innovation in package building and the improvement of integrated power control. More functions and larger chips have also more I/O. This requirement jointly with chip's size reduction push to much higher density of output leads.

The package trends for memory and ASIC for a few years behind and ahead show a strong pitch size evolution: Ball Grid Array (BGA) with 1.27 mm and 1 mm, Fine Pitch Ball Grid Array (FPBGA) with 0.8 mm, Chip Scale Package (CSP) with 0.5 mm and the Flip Chip (FC) with 0.25 mm and lower. Each of the above mentioned packages is under constant miniaturisation and cost reduction.

Under development are electroless bump deposition of Ni-Au, which is a low cost approach, and the Polymer Flip-Chip process (PFC) using silver-filled conductive bumps, which are stencil-printed. PFC bump patterns have successfully produced bumps as small as 50 μm on 100 μm pitch.

When power dissipation and low thermal resistance are concerned, BGA are replaced by Land Grid Array (LGA). That's the case of power and RF devices. These types of packages are used not only for large I/Os integrated circuits but also by manufacturers of transistors, diodes, voltage regulators.

What is the best package? Unfortunately there is no winner. Every company has its own favourite package. Today's applications require different permutations of materials and processes. This is leading to a multiplicity of packages and form factors. Any BGA, CSP, LGA packages and stacked 3D modules will be predominant in the near future.

The pitch size is constantly decreasing making assembly more and more critical. A soldering method with very fine pitch of BGA or CSP should be replaced by more tolerant anisotropic conductive adhesives. The mechanical requirements are rising too and to compensate TCE mismatch between different materials an underfill became unavoidable.

Therefore research laboratories work on the next generation of interconnects for chips. *Intel*'s Bumpless Buil-Up Layer (BBUL) technology will be used in the near future (2006-2007) for microprocessors with 20 GHz clock rate and more. This technology consists in establishing interconnects directly on the chip and eliminating the intermediate level which reduce electromagnetic parasitics, increase frequency bandwidth and improve power dissipation.

Batteries, fuel cells - Nomadic applications require lighter, thinner and lower cost batteries. Specialists estimated that the 3rd generation of cell-phones will require the energy density of 350-400 Wh/l versus 200-300 Wh/l today.

Fortunately, batteries progress in all directions. Although NiMH still presents about 50% of mobile phone, the lithium-ion (Li-ion) entered already to its maturity stage and it would be difficult to expect more than 400-500 Wh/l (160-180 Wh/kg). The lithium-ion polymer is the "star" today and its thickness is going down to 2.5-3 mm for mobile applications. The advantage of this technology is the possibility to realise almost any shape and relatively high energy density which achieved today between 170 and 300 Wh/l. Lithium-sulphure and LiMnO2 should allow to achieve the capacity of 380 Wh/l in 2001. Aluminium-air is another competitive technology which achieves 8 times higher energy density than lithium-ion.

Although batteries progress, it seems that Fuel Cells will be the future solution for nomadic equipment. The most popular are hydrogen (H_2) and methanol (MeOH) based solution. Many companies are working hard on this subject. This year a German company *Smart Fuel Cell* demonstrated the first methanol fuel cell able to generate 175 Wh from 175 ml methanol cartridge with 50 W of maximum power /8/. There are still many problems to be solved such as difficulty to control a chemical reaction, to eliminate products of reaction (CO_2, water) and to reduce volume and weight.

3. CONCLUSIONS

The coming years of the 21st century will bring a market and technology evolution which is difficult to predict on longer term. This paper indicated only some trends on relatively short term of 3 to 5 years. A few specialists say that after 2012 when the microelectronics will achieve a technology limit situated at 0.01 μm a major changes must occur to ensure the future evolution on actual level.

In the meantime, electronics industry will face a number of challenges and the industry landscape will change significantly. System-on-a-chip (SOC) are favoured for reasons of manufacturing cost, performance and Intellectual Property (IP) protection. Hardware/software co-design is in need of real-time simulation.

Challenges faced by all industry sectors such as technical performances, quality, cost and time-to-market generate many other, more subtle challenges that are faced by companies engineers and managers. They are being pressed from all directions: improve their product's performance, reduce costs, get it done faster, keep a high profitability, satisfy customers and shareholders. The today's engineers and managers need to have a technical expertise, a very good knowledge of the market, a high innovation potential, a quality approach, managerial skills and a high resistance to stresses.

This is a formidable challenge for today's electronics industry faced with systems and technologies in perpetual evolution. Information, training and support will be the key elements for companies to complete projects and keep their competitive lead. Electronics products will in the future need a global approach to track them from the design stage through to their end of life and recycling.

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