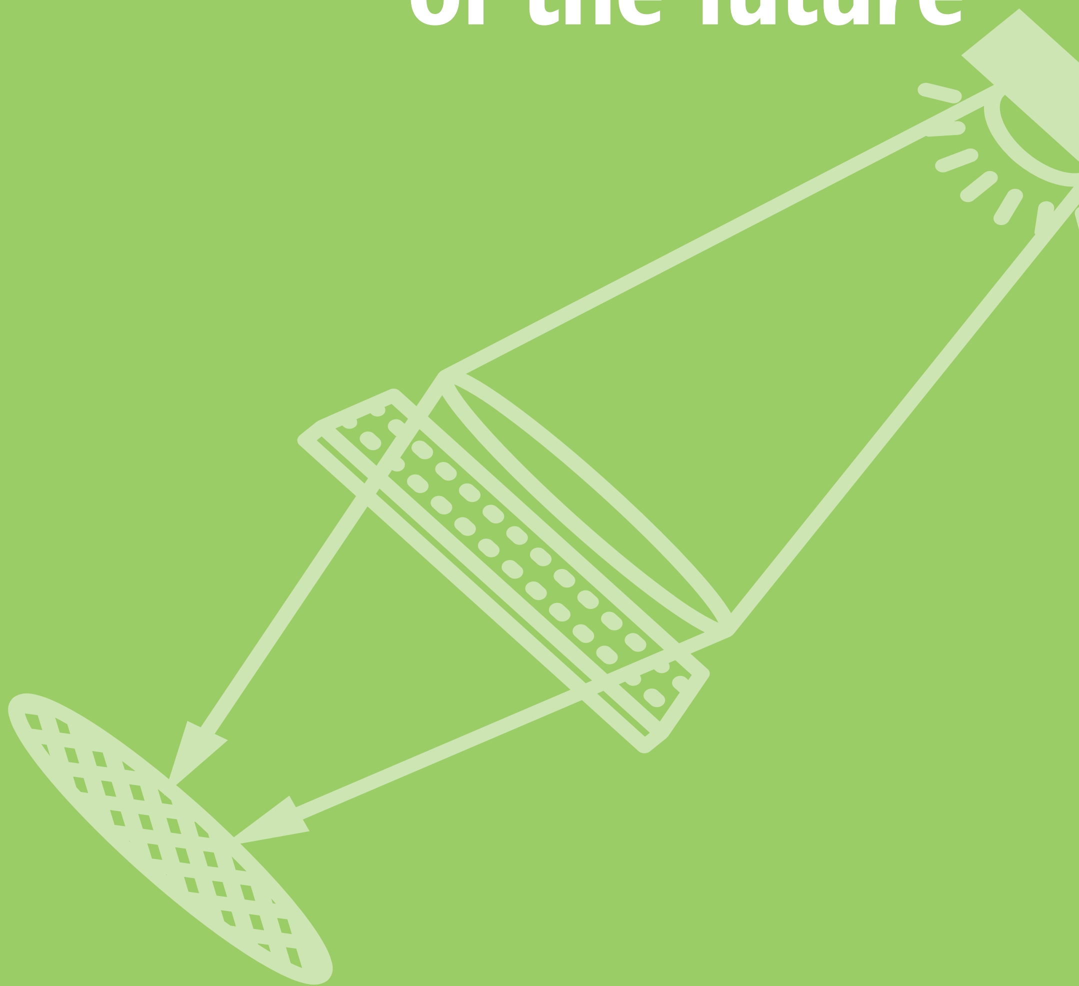
PROGRAMME SUCCESSES

MEDEA+

Detailing the circuits of the future



EUREKA


Downsizing
More Moore
Alternative ways
1st way
2nd way
DUV Immersion 193 nm
Production capability
• today: 45 nm
• tomorrow: 38-32 nm
(with or without double exposure)
NVG
EUV 13.5 nm
only prototype / production tool
started with EXEPT
Target: 32 nm to 22 nm
Concept: <22 nm
Nanoimprint demonstration to be
clearly done
(throughput / defectivity)

Detailing the circuits of the future

Optical photolithography is a key stage in the manufacture of microelectronic devices. As each new generation of devices becomes ever smaller, so do the line widths and minimum feature sizes. Competition in front-end wafer-fabrication equipment is particularly high as the machines are highly expensive. However, the market for photolithography is dominated by a European consortium, largely as a result of collaborative projects within the MEDEA+ and predecessor MEDEA Cluster programmes. The MEDEA+ programme has already prepared the way for use of extreme ultraviolet (EUV) lithography in full-scale production – possibly already for the next generation of 32 nm and below circuits. And it has studied potential alternatives such as UV-based nanoimprint lithography.

Optical photolithography now accounts for 35% of the fabrication cost of silicon chips. The process involves projecting light through a photomask to form an image of the desired circuit on the silicon wafer, coated with a light-sensitive photoresist. Following development, exposed areas are washed away, making it possible to etch circuit details on the wafer surface. The latest state-of-the-art CMOS semiconductor chip can now undergo up to 50 such steps during the fabrication process.

Cutting the size of features on an electronic chip is important as it makes it possible to integrate ever more functionality and memory on the same area. Reducing dimensions from the 65 nm now in production to 32 nm and below by 2010 would typically mean four times more memory could be provided for a digital camera, processors could halve in size while doubling speed, or devices made smaller to reduce power dissipation and to permit a higher yield.

However, as circuit details become ever smaller, the wavelength of the light has also reduced and is now reaching the limits of the deep ultraviolet (DUV). While the current wavelength is 193 nm, the solution for future generations of much smaller circuits is possibly extreme ultraviolet (EUV) with a wavelength of 13.5 nm – actually soft X-rays.

New processes involve much more than simply changing the projection system. MEDEA+ has therefore been involved in work on developing the technology and processing infrastructure to enable the introduction of EUV technologies with totally new equipment and infrastructures, while continuing to extend the use of 193 nm DUV through application of immersion technologies with or without double exposure that could increase the resolution of existing systems. In parallel, it has also initiated work on alternative technologies, particularly nanoimprint, which offers a lower cost approach but with much lower production throughputs.

Pooling European knowledge on EUV

Full-scale manufacture using EUV technology requires progress in several areas, including: light sources, optics, metrology, contamination control, masks and mask handling, and process chemicals. MEDEA+ therefore established a series of four projects in EUV technology bringing together Europe's leading companies and research centres in wafer steppers, light sources, imaging systems and mask manufacturing to help win the global race for next-generation lithography (NGL) solutions.

The objective was to provide NGL manufacturing capability at 45 nm feature size nodes, able to supersede DUV lithography that was thought at the time to be reaching its limit in the production of circuits with details down to 65 nm.

Collaboration between the four projects was guided by the MEDEA+ EUV Cluster Steering Council (CSC). The CSC offered several important advantages: assuring an optimal trade-off between individual consortium creativity and initiatives, and the closely monitored project

co-operation and cross-fertilisation within the framework of MEDEA+; and speeding and intensifying the information flow within the project consortia.
Involvement in MEDEA+ also improved dissemination of project results, providing a powerful means of spreading news about Europe's achievements in EUV lithography to the world. This has made it possible to boost the impact and image of Europe's EUV lithography engagement on the international stage, impressing US and Asian competitors and potential customers alike.

Four main elements for EUV

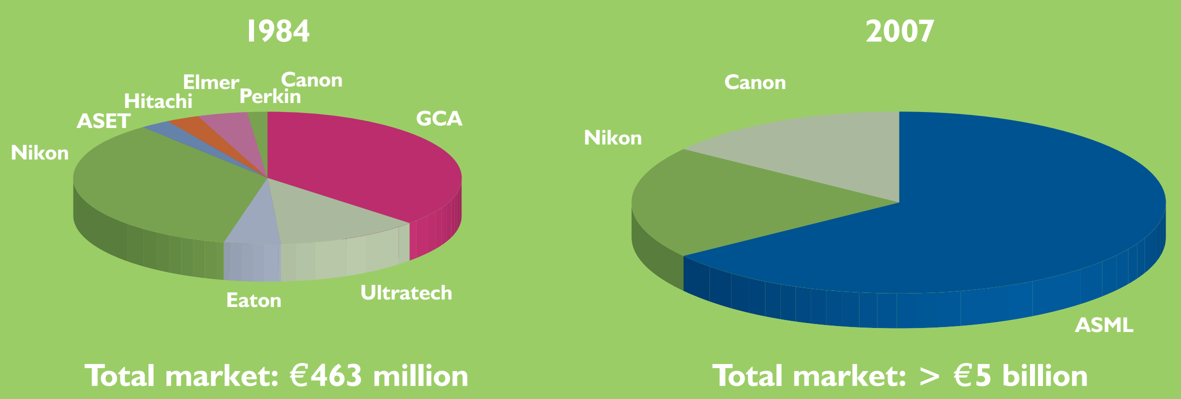
The EUV projects covered four main elements of the lithography process: tools, masks, light sources and processing. Extensive work on optics and coating technologies in the MEDEA+ T403 EXTATIC project led to the development of an EUV lithographic research tool essential for future work in this area. As a result, two such 'alpha' tools were delivered to research centres in Europe and the USA in 2006 to continue this effort.
A complete mask-making process for 45 nm circuit structures and below was developed in the MEDEA+ T404 EXTUMASK project, based on 13.5 nm wavelength EUV. The project also developed the tools necessary for mask metrology inspection and repair. As a result, it was possible to deliver the first commercial masks to the Netherlands-based global leader in lithography equipment for chipmaking.
The MEDEA+ T405 EUV Sources project examined two main approaches to EUV illumination: gas-discharge and laser excitation. It focused on the former as lasers proved too complex and expensive. At EUV levels, optical materials are no longer transparent and so the optical system consists of mirrors that reflect only 70% of the light – the optical system absorbs the rest. A major increase in power levels was required and EUV Sources achieved world record outputs, meaning such sources are no longer a block.
Finally, the MEDEA+ T406 EXCITE project set out to eliminate bottlenecks related to EUV imaging for full-field patterning development, building on the results of the source, mask and tools projects.

Moving to EUV volume production

Results of the EUVL projects cluster and the EU Sixth

Leadership in equipment and materials

Lithography costs have grown dramatically over the past decade and are now the most important cost element in the semiconductor fabrication plant. A wafer 'stepper' used to project circuit images can now cost between €30 and €40 million. And these costs will rise for future generations of devices. However, European equipment and material suppliers have established themselves as world leaders in the crucial strategic lithography sector in the past 20 years.



Source: ASML/ MEDEA+

Framework Programme MORE MOORE project served as the basis for the MEDEA+ 2T301 EAGLE project. This set out to resolve outstanding problems in collector lifetime, masks and photoresists that would make it possible to extend EUV lithography to even smaller feature sizes in full-scale production. The main goal was the development of a complete lithographic platform for the volume manufacture of 32 nm node semiconductor devices by 2009 in line with the International Technology Roadmap for Semiconductors (ITRS).

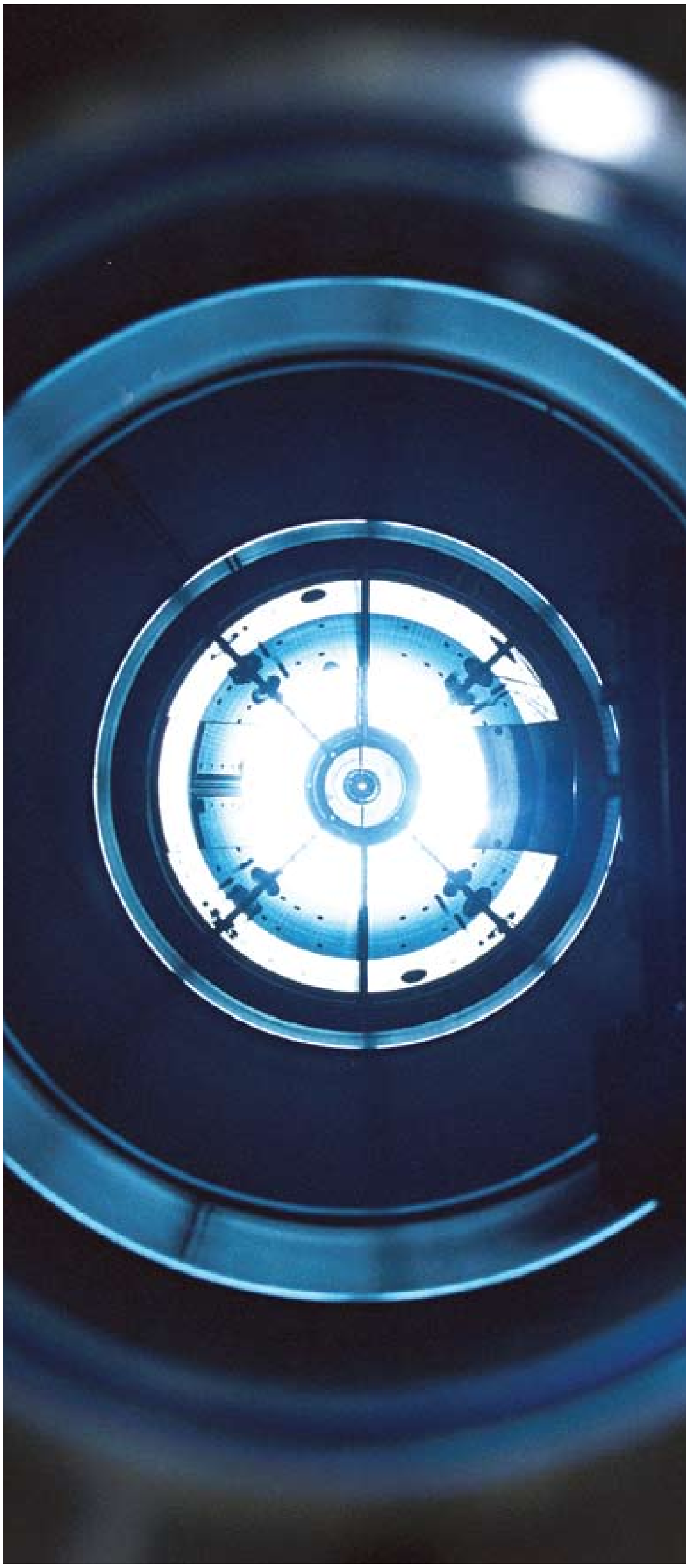
This required technological developments in critical subsystems such as handling and sensor systems, optics, collectors and sources to build a system qualified for use in a high-volume semiconductor fab. EAGLE brought together optical system producers, reflective coatings specialists, gas/vacuum systems experts, and EUV source and collector manufacturers.

The project concentrated on the critical areas for volume manufacturing with special emphasis on cost of ownership. It has focused on:

1. EUV lithographic tool system architecture design and integration;
2. Design and development of the illumination system and improvement of the projection optics, at-wavelength metrology and multilayer coatings for the EUV optics; and
3. Source collector module specification, qualification and integration, collector and coating design optimisation, collector material and multilayer coating development, collector cleaning, debris reduction and optics lifetime improvement.

Targets for system design and prototyping focused on the requirements for 32 nm node high-volume production with an initial system throughput of 40 wafers/hour, upgradeable to over 100 wafers/hour. The platform should be applicable to at least 22 nm node requirements in terms of alignment, focus and both image and wavefront sensors.

Results of this project will also be extendable to even smaller resolutions – at least as far as the 16 nm node – and so help Europe secure global leadership in the EUV lithography market to serve the microelectronics industry for the next decade.



A lower cost alternative?

Early access to advanced lithography technology is vital for European competitiveness. Emerging ultraviolet (UV) nanoimprint technology offers a potentially different and cheaper approach to next-generation lithography for high-resolution micro- and nanoelectronics applications. The MEDEA+ 2T305 FANTASTIC project is evaluating all aspects of this new technique – both technical and economic – for the 32 nm half-pitch technology level and beyond. Success could open up an alternative to extreme ultraviolet lithography for future wafer-patterning processes.

UV nanoimprint uses mechanical embossing to print circuit patterns with resolutions beyond the limitations caused by light diffraction or beam scattering in conventional optical lithography. After imprinting, the patterned polymer resist is cured by UV light projected through the quartz mask or template, hardening into the device patterns required for etching. Patterns are written using an electron beam with the same line width as the pattern on the wafer rather than reducing it by four times as with conventional optical lithography.

Nanoimprinting enables patterning of features below 32 nm half pitch and offers a 3D printing capability. In addition to reducing tool complexity, the process environmental requirements are markedly lower than with optical lithography. And, by avoiding expensive optics and cumbersome enhancement techniques such as phase-shift masks, the machines can cost far less than current step-and-scan systems. However, throughput is very low – currently around five wafers an hour; defect prevention and overlay accuracy are also problems.

FANTASTIC is assessing technological ability, the effort required to provide manufacturing solutions and the potential cost of ownership. If the project clearly demonstrates the potential of the technology at the sub-50 nm half pitch, a follow-up project is planned to establish the full infrastructure for volume production at 32 nm.

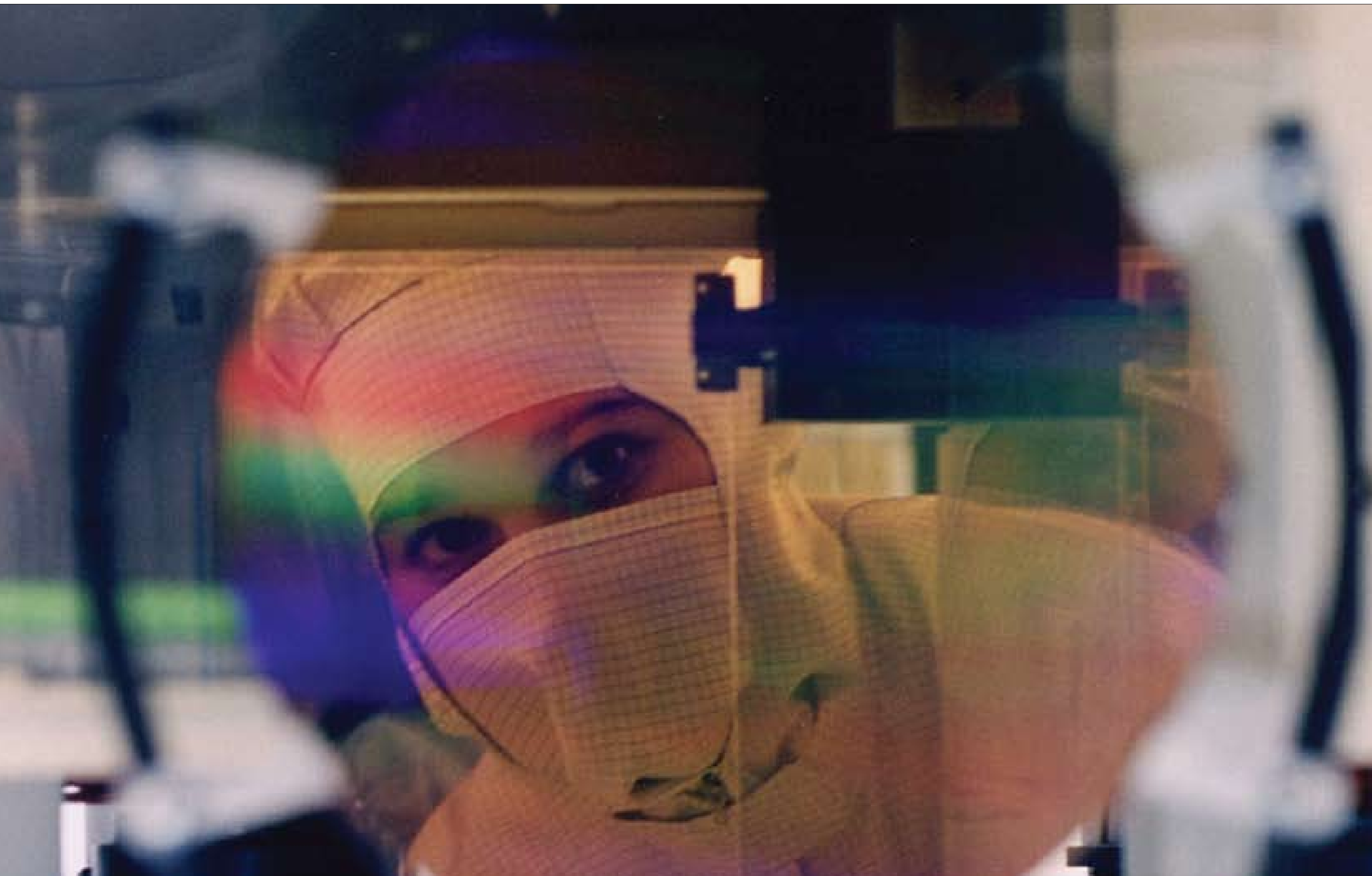
Extending immersion lithography

Immersion lithography replaces the air between the projection lens of the imaging system and the silicon wafer with a layer of fluid. This fluid refracts or bends the light, resulting in a greater resolution because the lens can be designed with a numerical aperture greater than one. This makes possible smaller features as the larger the aperture, the better the resolution.

While originally thought suitable for circuit details down to the 65 nm node, development of immersion processes has extended use of 193 nm wavelength technologies to the 45 nm node – but at a high cost in terms of equipment and productivity. To achieve details of this size either requires double 'patterning' – double exposure – that needs twice as many masks and cuts manufacturing throughput by half or wet lithography with complex optical proximity correction (OPC).

The MEDEA+ 2T304 LIQUID project set out to extend the 193 nm optical lithography platform to process devices at the 50 nm feature level and below using immersion lithography. The goal was to develop the infrastructure to support volume production. The project is well on track to support half-pitch resolutions between 60 and 38 nm, with systems already commercialised using the results. And development has started on solutions for 38 to 32 nm half-pitch resolutions.

Pushing the limits of existing optical lithography technologies is essential. The cost of ownership of the 193 nm process has been reduced since initial introduction. It is now a mature technology with good availability of photoresists and reasonable reticle quality. Extending use of 193 nm processes over at least two more nodes will dramatically reduce the cost of introducing new generations in wafer-fabrication plants.



Muscling in on mask supply

Lithography mask sets play an essential role in imaging performance and strongly contribute to costs, quality and yield of the process. Average mask-set costs increased from € 160,000 for 120 nm technology to between € 1.2 and € 2.4 million for 45 nm technology with global mask sales of € 2.5 billion in 2006. Roughly 30% of costs can be attributed to logistics and related in-line management in a non-standardised mask supply chain, leaving substantial room for savings.

Short cycle times through the mask supply chain are crucial for early product availability. However, most chipmakers spun-off their in-house mask shops at the end of the 1990s, leading to increased complexity with an external multi-party supply chain, including exorbitant data flows and lack of direct control over quality and cycle time.

The MEDEA+ 2T302 MUSCLE project developed a photo-mask supply chain model that allows calculation of the impact of all supply-chain changes on overall cycle time by analysing six key process indicators in 53 steps. A cycle-time reduction of around 10% was demonstrated at the end of the project. Evenly applied to all masks consumed in the EU, this could save European chipmakers some € 50 million a year.

Some of the results of the MUSCLE project are now being used in the MEDEA+ 2T307 CRYSTAL project. The goals of the CRYSTAL project are to more than halve the cycle time and reduce excursion risk by at least 50%.

Focusing on enabling technologies

Shrinking of structures will continue to be a main driver for technology in the coming decade. Lithography is the key enabler for further reduction of feature sizes. Enabling-technology projects are essential building blocks for the new CATRENE nanoelectronics Cluster. As part of its focus on manufacturing science, CATRENE intends to work on cross-cutting technologies, equipment and materials. This work will include:

- 193 nm lithography for 32 nm half-pitch, including all related infrastructures;
- EUV lithography for 32 and 22 nm half-pitch, including all related infrastructures;
- Maskless lithography: optical, e-beam or other concepts; and
- Alternative lithography concepts such as nanoimprint and light sources with imaging wavelength below 13 nm.

CATRENE
Cluster for Application and Technology Research in Europe on NanoElectronics

MEDEA+

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MEDEA+ Σ!2365 (2001 to 2008) was the industry-driven pan-European programme for advanced co-operative R&D in microelectronics. Its aim was to make Europe the global leader in systems innovation on silicon. Some 90 projects were labelled, covering challenges in microelectronics applications and enabling technologies, and involving 2500 scientists and engineers annually from 23 European countries. The more than 600 partners included major microelectronics manufacturers, systems houses, SMEs, universities and institutes.