Bringing Multi-Domain Functions to Intelligent Systems through MEMS Technology Platforms – The INTEGRAMplus Access Service

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Introduction
Nanotechnology embraces many disciplines, devices and materials. These range from very deep submicron electronic devices including carbon nanotubes, resonant tunnelling devices, and next generation CMOS, through to functional materials such as bio-chemical monolayers and self-assembling molecules. It is widely recognised that to extract the performance benefits from these technologies, suitable carriers and interfaces must be developed to support delivery of electrical or physical input and output and provide a "quiet" electromagnetic and mechanical environment for the active structures.

The FP6 Europractice-like Service Project 'INTEGRAMplus' aims to provide industrial and academic access to multi-technology MEMS platforms that target both today's requirements for products based on Microsystems Technologies and tomorrow's trends towards the exploitation of nanotechnology for new functionality within electronic systems.

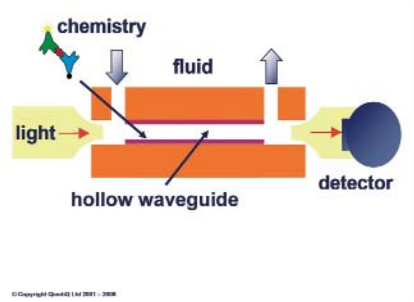
The INTEGRAMplus technology base is focused on the integration of polymer and silicon technologies. In general the concept is to use polymers for both packaging of active silicon-based devices and to provide fluidic interfaces and delivery functions to silicon-based bio-chemical sensors. This article presents the foundations of the INTEGRAMplus technologies and vision together with potential applications.

Multi-domain Technology
QinetiQ has developed a silicon-based technology that can be used in the electrical, fluidic and optical domains. This unique patented technology, "Hollow Waveguide" (HWG), was originally developed to provide an optical platform for hybrid and monolithic integration of passive and active devices. Hollow waveguides are fabricated by controlled deep-dry etching using DRIE of a silicon wafer to produce channels which guide the light and provide low-loss single-mode transmission. The fourth wall of the waveguide is formed using a lid fabricated from the same material which may also be used to house drive electronics. Hollow waveguides with metallic inner wall coatings exhibit broad waveband, high power, transmission characteristics in conjunction with low polarisation-dependent loss (<0.1 dB/cm). The etch process also provides monolithic optical functions such as splitters, recombiners, switches, filters, etc, as well as alignment slots for easy placement of discrete components. Complete integrated optical circuits can be formed in which the hollow waveguides guide light from one discrete (or monolithic) component to another. Positive light guidance in the HWG channels relaxes component alignment tolerances enabling the use of standard pick-and-place techniques for high speed, low-cost automated assembly, without the need for active alignment.

Fig. 1 illustrates the use of hollow waveguides to provide a development platform, 'Bio-canal', that provides the ability to perform complex optical functions in a microfluidic environment. An optical sensing mechanism would normally be used that may be tailored to a wide range of individual applications. For example, the light output may be directly modulated by binding of specific molecules/cells to the walls coated with a given surface chemistry (with potential for interferometer analysis for enhanced sensitivity). Alternatively, by using specific tags, a fluorescence-based detection scheme could be implemented or the platform could be used for cell cytometry. The underlying core technology remains the same, but the sensing mechanism changes between applications.

Combining HWG with polymer-based fluidic delivery and packaging opens a range of opportunities. As the active technology is silicon-based, implementation of a design environment based on existing tools is feasible with guidelines and libraries containing pre-designed parameterisable functions realistic. These libraries can contain a range of MEMS-based silicon electrostatic/ thermal actuators, electronic functions for signal processing/ read-out and nano-scale surface chemistries. These technologies will be offered to users of the INTEGRAMplus service in several standard configurations.

Multi-technology Integration
In order to offer a complete and competent service, the INTEGRAMplus multi-technology integration activities will address a range of specific processes in addition to access to HWG technology. These include:



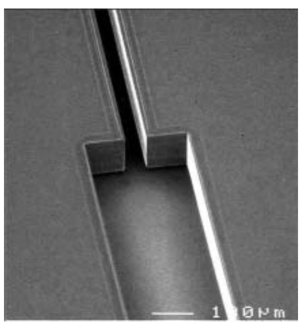


Figure 1: Left: schematic of hollow waveguide combined bio-optical-fluidic platform; right: SEM of deep-dry etched channel and MMI splitter

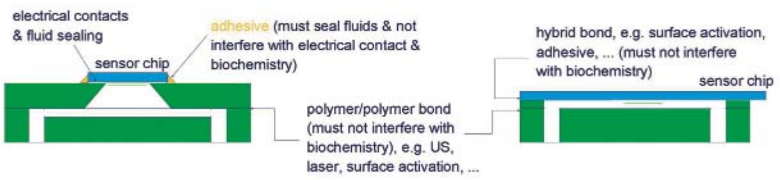


Figure 2: Schematic of targeted hybrid integration components.

- Si chip fabrication
- Microchannel fabrication
- Optical and microfluidic components
- Physical transducers
- Surface functionalisation
- Channel sealing
- Optical and microfluidic interfacing
- Electronic integration

These competencies require the development of a combination of important technologies. Chips with electrodes and polymer parts with electrical leads will be supported. Microstructured gaskets that use casting, laser cutting and punching, and polymer parts fabricated via micromachining, casting, embossing or injection moulding are an important component of the service offer. Bonding technologies that include the electrical contacts between chip and leads based on flip-chip, solder bumps and wire bonding, as well as hybrid bonding technologies using surface activation and thermal bonding, will be offered. Adhesive bonding techniques based on glues and double-sided sticky tape will also be available for specific applications. Key processes will support connection to the macro-world (fluid ports and reservoirs, electrical contacts, optical contacts) and the fabrication of silicon/SOI parts using DRIE, anisotropic wet etch, and chemical vapour etch.

As an illustration of the INTEGRAMplus multi-domain integration concept, a target microsystem is illustrated in Fig. 2. This example requires microfluidic channels, polymer-polymer or hybrid bonds, surface functionalisation, electrical contacts to a sensor in a flip-chip configuration, and an adhesive underfill for sealing.

Design Tools and Virtual Manufacturing

A design methodology is made available in INTEGRAMplus providing a CAD environment for the design of MEMS components and associated electronics. In addition, the package design is considered early in the design cycle so that design iterations can be minimised. The development of increasingly sophisticated microsystems based on mixed silicon-polymer technologies requires system simulations that encompass even more physical domains. In order to understand the complex interactions between these domains, and the impact of manufacturing variations from one domain to another, multi-domain modelling and/or co-simulation is needed. Two commonly used methods of implementing a multi-domain system simulation are behaviour model-based circuit simulation (e.g. Coventor's ARCHITECTTM) and signal-flow simulation (e.g. MathWorks' Matlab-Simulink®). Both types of system simulation are combined to simulate not only MEMS and ICs, but also more complex multi-domain mixed-technology systems. The INTEGRAMplus design environment offers an implementation of a Design for Manufacture methodology that supports designers in the process of handling constraints relating to manufacturability and facilitates interaction with other development groups (see Fig. 3).

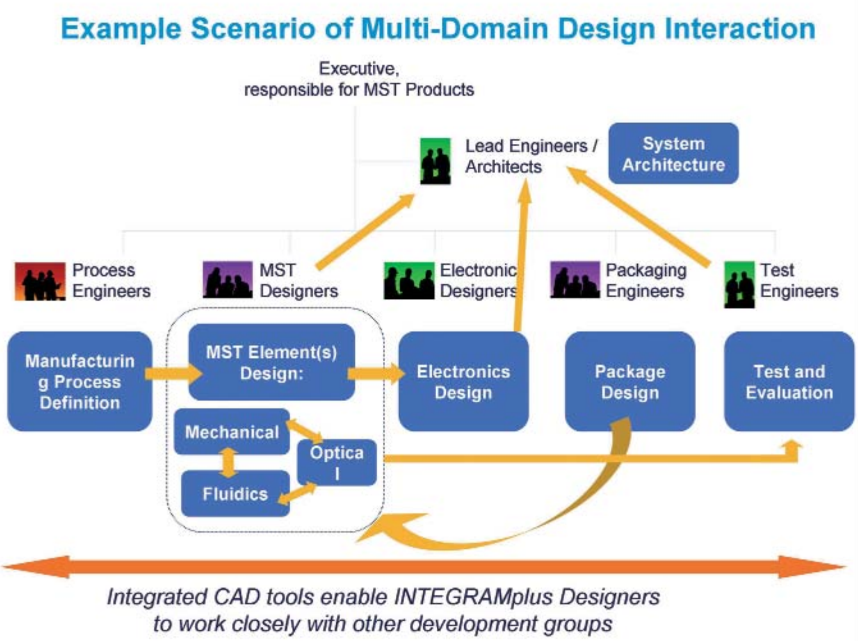
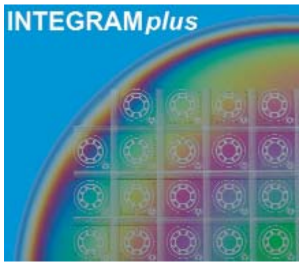


Figure 3: INTEGRAMplus design environment

Future Developments

The combination of nanotechnology, biology, advanced materials and photonics opens the possibility of detecting and manipulating atoms and molecules using nano-devices with a broad application area, including healthcare and environmental monitoring. The main bio-active components currently used in bio-devices are: enzymes, antibodies, cells (micro-organisms, tissues), nucleic acids and lipids. The key issues are the integration and compatibility of such sensing layers with the host technology. When a sensor array is envisaged, each sensor having different functionalities, the problem is compounded. Therefore the key areas to be addressed for bio-integration are the interface between bio-materials and the surrounding sensing platform (e.g. silicon/polymer) and compatibility issues. Thus the compatibility of bio-materials with technological processes for device fabrication, thermal budget, immobilisation techniques, functionalised surface and adhesion will be considered for offering standard processes for bio-medical device fabrication and bio-integration. The combination of material and multi-domain know-how, for example from optical to fluidic, will make possible the development of innovative solutions not yet available for devices such as lab-on-a-chip, that can be applied to a broad range of applications in biology, chemistry, industrial process control and security.

How to access INTEGRAMplus
INTEGRAMplus services can be accessed at any point of the product development life cycle, from consultancy and design through proof of concept to prototyping and manufacture. The consortium brings together a powerful combination of technologies and competencies from 10 key European players, together with associated supply chain partners. The INTEGRAMplus Office will advise on the best combination of the partners for customer requirements. Please visit the website www.integramplus.com or email info@integramplus.com.



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MEMS-pie: The Integration of Piezo-electric Thin Films In A SOI- MEMS Process

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Reliable technology for integration of piezoelectric thin films is a key tool in the realization of new products based on piezoelectric microsystems. Industries that use piezoelectric thick film or bulk elements in their existing products see a need for smaller devices with improved functionality and reduced energy consumption. MEMS developers need technology that can deliver powerful and efficient actuation for the next generation of MEMS devices. We regard this as a "down-to-earth" marriage of nano- and micro-technology. The key piezoelectric properties of the PZT films require nano-scale control of chemistry and micro-structure, while the silicon-based device itself is state-of-the-art MEMS technology.

Introduction
The reliable integration of piezoelectric thin films into MEMS on an industrial scale is a key enabling technology for a wide range of future products. Examples include ultrasonic imaging transducers, pressure and flow sensors, accelerometers, acoustic wave devices, micro-motors, micro-pumps, and micro-sensors for chemical analysis. PZT thin film fabricated by chemical solution deposition (CSD) provides the best material properties although both sputtering techniques (for PZT and aluminium nitride) and pulsed laser deposition (PZT) are relevant techniques for some applications. SINTEF MiNalab expects to offer this capability to selected customers by the end of 2007. This is a result of close cooperation with our partners in the MEMS-pie project, which has a focus on transferring scientific and technological knowledge obtained in academic laboratories to full production level.

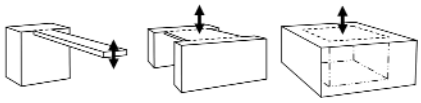

Figure 1: Basic designs of piezoelectric multimorph actuators, utilizing the transverse piezoelectric effect; (from left) cantilever, bridge and fixed membrane.

Design and Modeling
The most commonly employed configuration for piezoelectric thin film elements in Silicon based MEMS is to integrate it as one of several layers of different materials in a multimorph or heteromorph structure. The film is sandwiched between thin metal electrodes. When a voltage or an oscillating signal is applied between the electrodes, the film changes dimensions both in the direction normal to the film plane (thickness mode) and in the plane parallel to the film (transverse mode). To obtain larger deflections

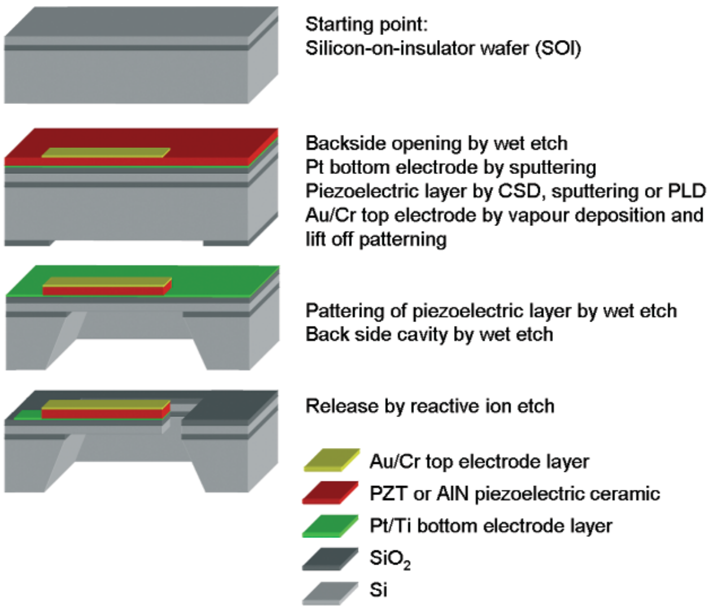

Figure 2: Main processing steps for the multimorph cantilevers. The SOI wafer is first thermally oxidized, and the rear side oxide was then opened using a lithographic mask and wet etching by HF. On the front side, a thin TiO2/Ti layer deposited for adhesion, followed by Pt bottom electrode deposition and piezoelectric thin film deposition. PZT is patterned by etching in HCl/HF, and the rear side cavity is opened by TMAH. The rear side etch stops at the buried oxide layer, which is then removed by HF. Finally, the cantilever is released by reactive ion etching.