Deliverable Report

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Executive summary:

The deliverable D39 task is reporting the recent external communication actions aiming to commercially exploit the innovative results of MAC-TFC proposal. The report includes the synthesis of actions engaged by the partners OSA to create the group of potential industrial end users for MAC-TFC technologies as our participation to the COWIN Smart Systems Market Place meeting at Helsinki. The targeted communication actions are mainly directed to the following communities:

1. Potential users in the candidate application domains, such Telecommunication, Power industry, Civil Security / Defence communication and Seismic exploration.

2. Potential partners in the view of the industrial exploitation of the technology, namely partners for the fabrication of VCSELs, Cs micro-cell and package assembly in LTCC. The target is here to enable a successful industrialisation of atomic clock product.

Successful industrialisation includes the following challenges:
- Achieve performance and reliability (10 years MTBF)
- Achieve cost target in volume production
- Commercial product availability in series at price target before US competition

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Document Approvals

Role	Name	Signature	Date
Document Editor	Alain Michaud		29/7/2011
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Contributing partners

Group	Name(s)	Role
OSA	A. Michaud	Leader
UFC-P5	C.Gorecki& N. Passilly	Preparation & presentation at COWIN meeting

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1. Work Progress and Achievements

1.1 Overview of the progress of the work

While by nature the communication to potential users and possible technology partners should occur once a demonstrator is available, the team has anticipated communication so to not loose valuable time.

As time to market is a critical issue on this project (see D40), the team is bound to accelerate any step toward a commercial product, namely:

1. Development of an alternative PP demonstrator (not included in original MAC-TFC program, see deliverable D58 – WP7) to prove the concept and moreover to generate interest of partners.

2. Introduction of the technology to potential users, short list of key players by application domain,

3. Start selection process of the first technology partners for the industrialisation of the first generation of MAC-TFC

In this way and before any demonstrator is available for showing the team has achieved several key steps as mentioned under 2 and 3.

1.2 Selection of the first application domains according to market analysis (see D40)

- Telecommunication wireless, provide superior Holdover to LTE base stations.
- Electricity Smart Grid applications, communication and phase meters
- PMR: Professional Mobile Radio TETRA for Civil security and Defence communication
- Seismic exploration

1.3 Key technology users by application domains

1.3.1 Short list of key technology users

- Telecommunication wireless:
  - MOTOROLA, Fort worth, Texas
  - NOKIA, Helsinki, Finland

- Power Smart Grid applications:

  The market analysis in progress at Oscilloquartz with outcome planned in early Q4 2011.

- PMR: Professional Mobile Radio TETRA for Civil security and Defence communication:

  - CASSIDIAN SYSTEMS, Finland & France
  - SELEX, Italy
  - BABCOCK, UK, Defence & Security division, Marine & Technology division

- Seismic exploration

  This is a second priority study that is not started yet.

1.3.2 Next steps

For all of the selected key technology providers generate a ad-hoc meeting:
- *Presentation of the demonstrator*
- *Collect customer key requirements for target applications*
- *Confirmation of customer interest to be involved in the evaluation of next versions of prototypes*

1.4 Participation to COWIN Market Place meeting at Helsinki

At the end of 2010, MAC-TFC proposal was selected for by the Commission as a high potential program the support from the European program COWIN. This initiative is dedicated to the commercial exploitation of advanced technologies developed in the framework of FP7 projects with the mission to individually support the selected projects in commercial exploitation of their innovative results. Our internal contact in COWIN is Régis Hamelin from EURIPIDES Office at Grenoble, France. From 14 to 16 June we was invited to the COWIN Smart Systems Market Place meeting at Helsinki. Three members of MAC-TFC consortium (UFC-P5: C. Gorecki and N. Passilly, OSA: A. Michaud) joined this event. C. Gorecki and N. Passilly presented the poster (see the Annex) to the visiting companies that attended the COWIN Marketplace. In addition, Mr. Hamelin organized for us a series of interviews discussions with selected MEMS foundries as well as MEMS integrated devices manufacturers, identified by COWIN to be interested in participation in mass production of future MAC-TFC product. During these discussions C. Gorecki and N. Passilly explained the general objectives of MAC –TFC while A. Michaud introduced the OSA target markets as well as the commercial strategy. We assisted to three meetings with potential industrial partners:

1) VTT MEMSFAB Ltd (http://www.vttmemsfab.fi) discussion with Hannu Kattelus (CEO):
VTT MEMSFAB was created last year by VTT Group as a legal separate entity that is using VTT existing manufacturing facility and focuses on commercial production of MEMS. Expects being break-even by end of 2011. At the actual step of development, VTT MEMSFAB business is based on 5 major products, mainly based on the VTT design, there are not yet the presence of industrial transfers from external sources. VTT MEMS confirms can handle medium size production 10K to 100K units / year.

2) **TRONICS (http://www.tronicsgroup.com), discussion with Stéphane Renard Founder and CTO).**
Tronics is an intenational MEMS Foundry with wafer fabs in Europe and USA, offering a broad portfolios of MEMS processes. This is a company of 50 people, 10 Mio Euro, based at Croles near Grenoble. Tronics confirmed a strong interest for both production of Cs cells and packaging.

3) ST MICROELECTRONICS (http://www.st.com), discussion with Jean-Paul Giry
Mr Giry is a manager at STM and member of EURIPIDES council. STM is world leader for production of MEMS, more in the XXL production scale. Clock market size is with 100K/year max is a small production for STM.

Evaluation after COWIN market place Helsinki:

All of these companies fit well with the identified targets. We will then actively contact them in order to plan meetings. In parallel, Mr Hamelin will continue to manage discussions with other MEMS foundries (Silex in Sweden, MFI in Germany, Colibrys in Switzerland and e2v in France) as well as companies specialized in packaging.

1.5 Synthetic list of potential industrial partners

The team started communication with candidate partners in the view of the industrial exploitation of the technology, namely partners for the fabrication of VCSELs, MEMS Cs cell and package assembly in LTCC. The target is here to enable a successful industrialisation, namely:

- Performance: Achieve target performance and reliability such as 10 years MTBF
- Cost: Achieve cost target in volume production to get a significant market share
- Time to Market: Commercial product availability in series at price target before US competition

With the support of COWIN the team already started a first selection of industrial partners for the first stage of the product industrialisation. It is critical to select partners who can offer the necessary flexibility in the early

stage to accommodate the many changes in design that will occur as the technology is not mature. Moreover it is essential to partner with medium size companies who can cope with limited volume series such as a few thousands series as opposed to a few million units series.

Already consulted / visited companies:

VTT MEMSFAB in Finland (interview at COWIN meeting)
Candidate for micromachining of MAC-TFC cells and LTCC package.
According to the specifications of VTT available automatic system of lithography this is not possible to handle the 1.4-mm thick wafers. To be evaluated.
VTT MEMS has limited capabilities of production. To be checked carefully.
The interest of VTT MEMS is not yet confirmed.

TRONICS MICROSYSTEMS in France (interview at COWIN meeting)
Candidate for production of CELL and LTCC package
Showed a true interest and are keen to bid for the project.
TRONICS is a serious candidate based on:
a) Company size (Medium), appropriate for medium size series
b) Capability demonstrated by production of MEMS for Harsh environment applications
c) Capability to optimize products (design capability)

ST Microelectronics in France (interview at COWIN meeting)
Candidate for production of CELL and LTCC package
STM is the MEMS world leader in numbers.
However this is questionable whether STM will be interested by and organised for small and medium size businesses.
STM interest is yet to be confirmed.

COLYBRIS in Switzerland
http://www.colibrys.com
Was visited by Oscilloquartz after COWIN market Place Helsinki.
Candidate for production of CELL and LTCC package
COLYBRIS is a serious candidate based on:
a) Proximity to Oscilloquartz
b) Demonstrated capability for production of MEMS for industrial applications including for harsh environment
c) Capability to optimize products (design capability)
d) Capability for both Medium and Large series

The team starts now a selection process.
As a next step, visits will be organised: a) to the candidates' factories to assess their capability further and b) to FEMTO-ST in Besançon to show to the short listed candidates the current production tool developed by FEMTO-ST for production of prototypes.

MAC-TFC : MEMS Atomic Clock for Timing, Frequency control & Communications

SEVENTH FRAMEWORK PROGRAMME

Atomic clocks provide enhanced accuracy, stability, and timing precision compared to quartz-based technologies. However, the size and power consumption of existing atomic clocks far exceeds those of quartz-based clocks, preventing their deployment in portable applications. The technology of Micro Electro Mechanical Systems (MEMS) provides substantial size and power reduction for frequency and timing references. Through MAC-TFC project addresses an original solution for MEMS-based atomic frequency references that will be the European version of chip scale atomic clock. To this aim, MAC-TFC brings together a consortium made of 5 major academic institutions, 2 research institutes and 3 industrial partners. The goal of the MAC-TFC proposal is to develop and demonstrate all the necessary technologies to achieve an **ultra-miniaturised**, **low-power Cs atomic clock**, using the principle of Coherent Population Trapping (CPT). It aims at developing the technologies of the building blocks for the micro-clock including a fully customised semiconductor laser, an innovative approach for filling the clock cell with alkali vapour and a low-power ASIC for RF electronics. It is also concentrated on the LTCC-packaging of the physic elements using two alternative configurations of the atomic resonator (T- and R-cell).

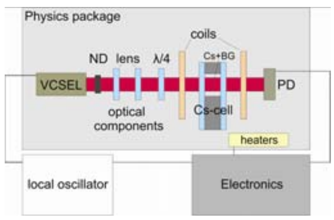
Goal: *P < 150mW, fractional frequency deviation < $6.10^{-10}\ \tau^{-1/2}$ (integration time τ <1h), < $1x10^{-11}\ \tau^{-1/2}$ (τ >1h)*

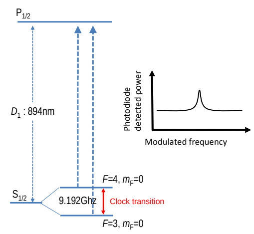
Applications: *Wireless synchronization, holdover modules, geo-localization, high-bandwidth communications*

Principle

➢ **Working Principle** is the Coherent Population Trapping (CPT) in which frequency stability of clock is based on transition between well-defined ground state hyperfine levels of alkali atoms. Laser diode frequency is modulated so that the optical spectrum contains two coherent sidebands separated by the hyperfine frequency.

1s=9192631770 Oscillations of Cs hyperfine frequency





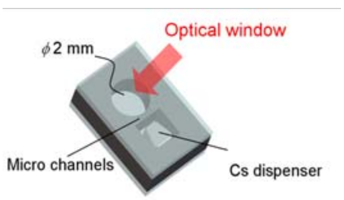
Coherent Population Trapping
- microwaves applied directly to high-bandwidth VCSEL laser
- no microwave cavity required

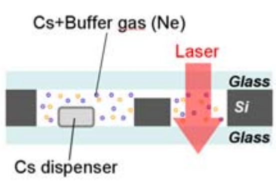
Use of alkali-metal atoms
- one valence electron
- easy production of atomic vapor (low melting point)

Buffer gases: ($Ne/N_2/Ar$) reduce CPT linewidth, preventing alkali atoms from wall-collisions

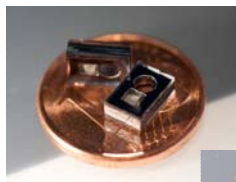
Cs-Cell

Transmissive cells (T-cell) are simple Cs-vapor cell which consists of the CPT detection cavity and the Cs dispenser cavity. The innovation in the fabrication technology is the process of filling the micro-cell with Cs vapor. This technique employs a Cs dispenser pill which is the mixture Cs compounds with the reducing agents as a source of Cs metal. The dispenser is stable up to 700°C and it is activated by local heating by laser, so that this process allow to fill the vapor of Cs after sealing the cell. This approach achieves perfect sealing of the cell and maintains the excellent quality of the internal atmosphere of the microcell.

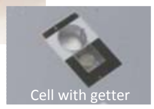




T-cells are fabricated by the technological key steps such as the etching of cavities on Si (deep reactive ion etching), sealing the glass/Si/glass sandwich structure by anodic bonding, and filling the cell with Cs using Cs dispensers.



Activated dispenser

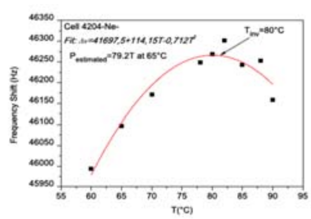


Cell with getter

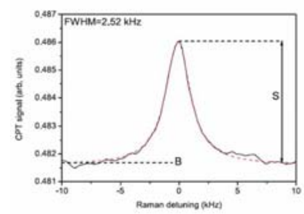
- Si wafer 1.4-mm thick
- glass wafers Borofloat 33 (Schott), 1mm thick
- Cs dispenser&thick film getter (SAES Getters)
- buffer gas & anti-relaxation coating

- cell cavity etch: DRIE + KOH
- buffer gas filling inside the bonder chamber
- sealing: two-step anodic bonding
- Cs dispenser activation: laser heating
- getter integration on glass cover improving the quality of internal atmosphere
- dicing

➢ **Performances** the T-cells lifetime at clock operation temperature is estimated to be > 3 years



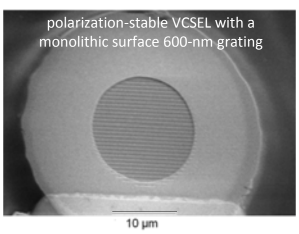
Demonstration of quadratic dependence on temperature of the CPT frequency (inversion temperature ~ 80°C)



- resonance linewidth: 2.5 kHz
- frequency stability: $1.5x10^{-10}$ at 1s

Customized VCSEL diodes

- single frequency operation
- wavelength: Cs D1 (894.35 nm)
- high-speed operation at low bias currents (0.5 mA)
- high modulation efficiency (> 5 GHz)
- polarization-stable VCSEL with a monolithic surface grating with 600 nm period
- high-temperature operation (80°C) with improved life time

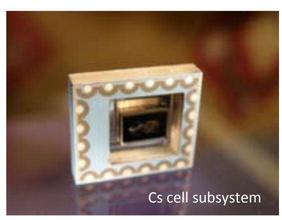


polarization-stable VCSEL with a monolithic surface 600-nm grating

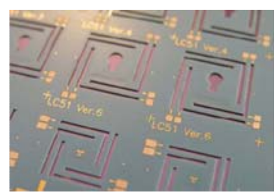
10 µm

Physics package in LTCC

- concept of microoptical bench including elementary components & electrical contacts



Cs cell subsystem



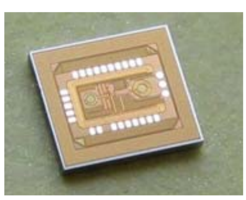
Thermally controllable multilayer LTCC platforms for Cs cells and VCSEL

- optimisation of thermal behaviour by use of bridge suspensions

Low power clock electronics

- implements four servos:
  - laser temperature
  - cell temperature
  - laser wavelength
  - local oscillator frequency
- further size reduction possible with ASIC

RF test board with bonded ASIC



ASIC (2x2 mm) for high resolution 4.6 GHz frequency synthesis

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