Recent Developments in RF MEMS in LETI

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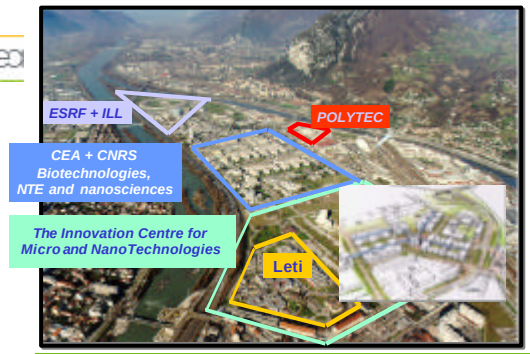
Outline

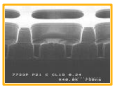
- RF MEMS Activities in LETI
- Film Bulk Acoustic Resonators
- Tunable capacitors
- RF MEMS Based Architectures
- RF MEMS Switches : thermal, electrostatic and magnetic
- Packaging
- Reliability
- RF MEMS Characterization
- Conclusion

LETI and the Future Innovation Centre MINATEC



Silicon Technology Department (DTS)

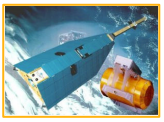
- 300 peoples
- 6000 m² clean-room
- CMOS/SOI, SiC, Microsystems, MOEMS, Packaging, Interconnections, RLC devices

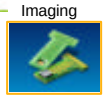


- RF MEMS Activities
  - 25 peoples
  - Mechanical Simulations and Characterizations
  - Sacrificial Layer
  - Wafer level and 0-level packaging
  - Magnetic, piezo, thermal, electrostatic actuations

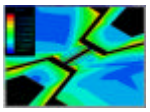
Information&Health Systems Department (DSIS)

- 200 peoples
- Smart cards, RFID, Adaptive Antennas, RF Design, CDMA, Sensors, Biochip, Medical Imaging





- RF MEMS Activities
  - 10 peoples
  - EM Simulations
  - RF Modeling
  - HF Characterization up to 65 GHz (Automatic Prober)
  - Design and Systems Architectures

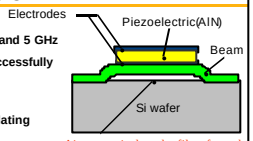


RF MEMS projects in LETI

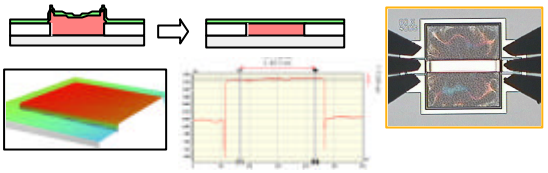
- Switch
  - **TCS21** (CNES, IRCOM) : Switch with electrostatic actuation (40V)
  - **AIC** (ST) : Switch with thermal actuation and electrostatic clamping in an Above IC approach
  - **Reliability** (CNES) : Studies on MEMS reliability
  - **ARHMS** (IST) : Thermal simulation and hermetic packaging studies for power switches
- Variable Capacitor
  - **Internal funding research** : Large tuning-range variable capacitor
  - **PhD student** : Support activity on design for an ST / EPFL thesis
- Bulk Acoustic Wave Resonator
  - **MARTINA** (IST) : Above IC FBAR – sacrificial layer technology, RF measurement, packaging
- MEMS Based Architecture
  - **MUMOR** (IST) : Development of models of MEMS devices for 3 G reconfigurable front-end

Film Bulk Acoustic Resonators

- IST Project MARTINA 2002-2005
- Goal : Develop Above-IC filters at 2.2 GHz and 5 GHz
- Prototypes of resonators have been successfully characterized at 2 GHz
- LETI is involved in :
  - Development of planarized insulating membrane and packaging
  - Physical & RF characterization
  - Filter design



Air gap to isolate the filter from the substrate

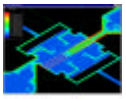


Tunable capacitors

- Internal research project
- Contact zipping action with an electrostatic actuation

Variation of contact surface = variation of capacitance

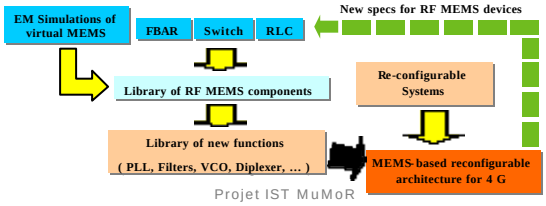
- Advantages of the design
  - Large variation of capacitance (no pull-in effect)
  - Small actuation voltages (large forces because small air gap)
  - Specific capacitance/voltage characteristic by re-design of the bottom electrode
  - Stability against environment
  - Suitable for Power applications



- First prototypes
  - Telecom applications
  - Capacitor range from 0.5 to 6 pF
  - Actuation Voltage < 10 volts (simulated)
  - Q of 18 to 55 @ 2 GHz (simulated)

RF MEMS Based Architectures

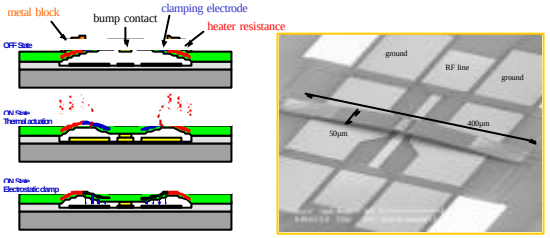
- Answer « Why and where RF MEMS can be used ? »
- Mixed approach : Systems requirements and technological know-how
- Idea :
  - Imagine and simulate new systems by taking advantage of the flexibility offer by existing and near-term virtual RF MEMS
  - In return, obtain new specifications for RF MEMS devices



Projet IST MuMoR

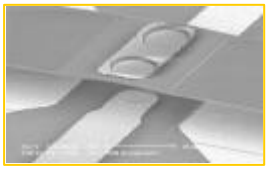
3 GHz Thermal-Electrostatic Switches

- Low voltage switch for reconfigurable multi-standard mobile phones
- Commutation sequence :
  - DC voltage on heater resistances ⇒ temperature rise
  - Beam deflection (bimorph effect) ⇒ electric contact (switch "ON")
  - Electrostatic latch ⇒ heating shutdown for a limitation of the consumption



3 GHz Thermal-Electrostatic Switches

Buckling of the beam before switching

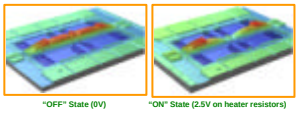


- Contact bumps : Details (gold lines, bumps)
- SEM & Optical microscope top view (heater resistors, metal blocks, gap)

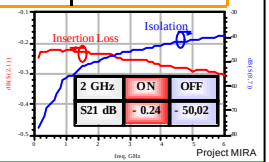
3 GHz Thermal-Electrostatic Switches

Main Results	Specifications	Results
Thermal actuation	< 3 volts	< 2 – 2.5 volts
Electrostatic latching	< 10 volts	> *15 volts*
Reliability	10^8 cycles	10^9 cycles (cold switching)
Commutation time	< 300 µs	~250µs
Insertion Loss @ 2 GHz	0.5 dB	0.3 dB
Isolation @ 2 GHz	40 dB	50 dB
RF Power @ 2 GHz	2 W	3 W
IP3	-	+ 44 dBm (limited by testbench)

- Interferometer and RF measurement



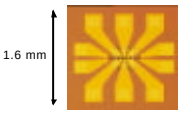
"OFF" State (0V) "ON" State (2.5V on heater resistors)

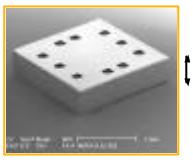


Project MIRA

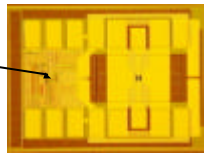
3 GHz Thermal-Electrostatic Switches

- Stand-alone prototypes
  - Project MIRA
  - Compatible with Flip-chip



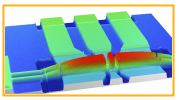


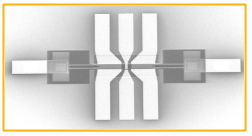
- Above-IC prototypes
  - Collaboration with ST Crolles
  - Integrated driver in BiCMOS7



30 GHz Electrostatic Switches

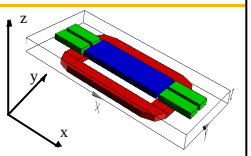
- Collaboration with CNES and Ircom
- Switches for LNA Redundancy : replacement of PIN diodes
- Electrostatic actuation
- Initial Specifications
  - 0.2 dB insertion loss
  - 40 dB isolation
  - Actuation voltage 40 volts
  - Long-term reliability : 15 years
- First measurements in June 2003

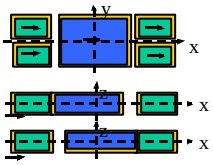




Magnetic Switches

- **Internal research project**
- **Advantages of the design**
  - Bistable operation
  - Very large forces
  - Very small actuation voltages (< 1 V)
  - Fast switching speed (< 20 µs)
- **Drawbacks** : High current pulse needed (1 A !)

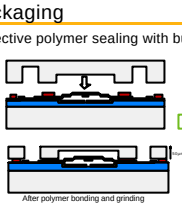


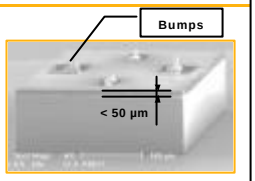


- First results and future works
  - A macro prototype has been demonstrated
  - Development of the process for magnetic layers are in progress
  - RF studies (EM simulations) are planed

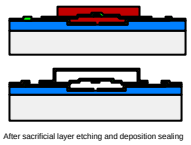
Packaging

- Collective polymer sealing with bumps





- Zero-level packaging

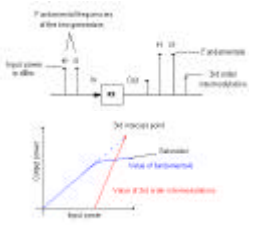


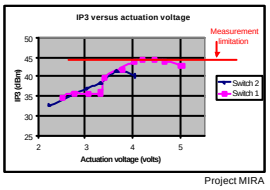
Reliability

- **Collaboration with the CNES**
- **Studies on the reliability of MEMS : Sensors and RF MEMS**
- **Examples of Works :**
  - Evolution of the materials characteristics
  - Mechanical reliability of the moving element
  - Effect of temperature and environment
- **French Research Network STRESSNET**
- **Studies on the materials for Micro and Nano technologies**
- **Examples of works :**
  - Normalized characterization procedures
  - Evaluation of materials characteristics

RF MEMS Characterization

- Mechanical characterization : laser interferometer
- High power RF measurements mixed with reliability studies
  - Development of an automatic probing station
- Measurement of very linear devices : IP3 up to + 70 dBm





Project MIRA

Conclusion and Future Works

- LETI offers a global technological and design know-how in RF MEMS
- Development and realization of new concepts of bistable switches
- Co-integration with high-Q passive devices : fully integrated RF front-end
- Technological developments for 200 mm transfer
- Development and realization of innovative RF MEMS based architectures
- Reconfigurable MEMS antennas

Contact and Bibliography

- You are welcome to visit the LETI !
- christophe.billard@cea.fr : RF aspects
- pierre-louis.charvet@cea.fr : Technological and mechanical aspects

- Project IST MuMoR : www.mumor.org
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- Ph. Robert & al."Integrated RF - MEMS Switch Based on a Combination of Thermal and Electrostatic Actuation', *to be published in Transducers 2003, Boston, June 812, 2003*