Potential of MEMS for space applications

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What is MEMS?

- MEMS = Micro Electro-Mechanical Systems
- Very small machine, Micro machine
- range in size from a micro to a centimeter
- combines mechanical and electrical structures

It is called “Micromachine” in Japan
Advantage of MEMS

- Small size and light weight
- Robust for the vibration and the shock of launch due to small mass
- Robust for radiation
MEMS in your life

• Head of ink jet printer
• DLP (Digital Light Processing) : in projector
• Accelerometer, gyroscope
  – In cars, digital cameras, game machines, cellular phone
• Pressure sensor
• Optical scanner
• And so much more …

Market in Japan: several hundreds billion yen
In the future, it will expand to several trillion yen
Coming soon

- MEMS microphone (Si microphone)
- RF switch
- Oscillator
  - SiTime, Discera
Promising space application

• Inertial sensor
  – accelerometer, gyroscope
• High frequency (RF) applications
• Optical sensor, mirror
• Etc..

I will mention RF device and inertia sensor next.
RF (Radio Frequency) applications

• High stable oscillator
  – For High precision measurement of distance and high quality communication
  – Ultra stable MEMS oscillator can be alternative to the quartz type USO (Ultra-Stable Oscillator)

• RF switch
  – Low loss, Low impedance
  – For phase shifter, TX-RX switch
MEMS Oscillator

- Alternative quartz oscillator
- The structure does not depend on the crystal orientation
- Smaller than the quartz oscillator with the same performance.
- Suitable for mass production
Possibility of MEMS OSC for space application

- If MEMS USO is realized, it can be alternative quartz type USO.
  - Deep space mission
  - rover

- The vibrator is robust for radiation due to mechanical structure. However control circuit is not robust.

  Reliability, stability and downsizing are required.
MEMS RF switch application

- TX-RX switching
- Phase shifter of phased array antenna
Features of MEMS RF switch

Disadvantages

• Slow switching speed (~1MHz)
• A few experiences
• Low reliability (recently, improved)

Advantages

• Low loss @ high frequency
• High ON-OFF contrast
• The performance does not depend on frequency

MEMS RF switch has more advantages at very high frequency (>10GHz) than others
Possibility of MEMS RF SW for space applications

- Smaller phase-shifter
- Robust for vibration and shock due to small size
- High robustness for radiation

RF switch is promising device for the space application
Inertia sensor

Requirements

- High stability
- High sensitivity

Applications

- Attitude control of the satellites and rover
- ION thruster acceleration measurement
- Moonquake observation
- Gravity measurement of small planets
MEMS accelerometer

- It can use attitude measurement of the rovers and the small explorers
- Poor performance for scientific observation and precise attitude control for the satellite
Gyroscope

- Poor performance for scientific observation and precise attitude control for the satellite
  - High Stability $< 0.1$ deg/h
  - High sensitivity $< 0.1$ deg/h
- It can use attitude measurement of the rovers and the small explorers
MEMS
in
JAXA

Some MEMS devices under study in JAXA
X-ray observation

Highly sensitive X-ray detector for X-ray astronomy
X-ray detector

- Temperature of the absorber is elevated by the impinging X-ray, which could be quantitatively measured in terms of the temperature.
- X-ray detector with PN junction temperature sensor is being used for SUZAKU (ASTRO-E2)
X-ray micro calorimeter

- Phase transition between super conductor and normal conductor is used to detect temperature.
Result

- Energy resolution : 4.81 eV (World record)
X-ray optics

- Dioptric system cannot be used for X-ray.
- To reduce the size and weight of the X-ray optics, micro pore optics has been developed.

Ezoe et al. 2005 SPIE, PATPEND

MEMS technology
Structure of the MEMS X-ray mirror

- The structure consists of tiny MEMS mirrors
- Downsizing of whole structure due to small mirror size and the space
- The silicon surface must be smooth
Fabrication and results

Fabricated mirror
Deposit SiN
SiN patterning
KOH etching
SiN remove

SiNx
Si

Silicone base
X-ray
X-ray

14 mirror chips
(a) 一回反射型 MEMS X 線集光系
Fabricated mirror
X-ray
Silicone base

100 mm
Reflection result

- X-ray reflection was observed by using this MEMS mirror
Landing laser radar

Two-dimensional Scanning Light Detection and Ranging (2D LIDAR) for altimeter on satellite.
System Configuration

MEMS scanner (ECO scan)

- Beam
- Magnet
- Reflection mirror
- Movable part

Timing Controller

- CFD
- Shutter Control
- Mirror Control
- LD Power

MEMS Shutter

Telecentric Optics

Scanning Angle (>10deg)

Passive Q-SW Nd:YAG

MEMS Mirror

MEMS shutter
Receiver configuration

Detector (APD)
Light 2
Opened shutter
Lens 2
MEMS shutter array
Light 1
Lens 1
Detector (APD)

MEMS shutter array
Micro actuators

Actuators Everywhere

- On small planet
- In small rover/satellite
- Alternative of electrical motor
For micro rover and explorer

- Gravity of planet is negligible.
- Weight of micro rover is very small
- Wheels are not efficient for maneuvering.
- In these case, inertia drive instead is useful for small planets explorer and small rover.
Impact Actuator

- Inertia-driven actuator
- Potential for micro/nano rover maneuvers
Driving principle
Advantage of the MEMS inertia drive actuator

• Act on the other objects
• Long driving displacement
• Large generation force
Other MEMS device in JAXA

• Inertia sensor (accelerometer, gyroscope)
• MEMS oscillator
• Etc…
Conclusions
Make it smaller
With nano-scale fabrication precision

• Reduced mass and volume of the satellite
  – High cost performance (Launch cost: ~1,000,000 yen/kg)
  – Reachable region depend on the satellite weight

• Multiple functions are integrated
  – Higher performance
Problems

• Harsh environment
• High reliability is required
• Most devices on the market are not for space application.
  – Newly development is required
  – Some of them can be used in space by re-packaging with MEMS technology.

High development cost
Frontier of MEMS

- In space and astronautical area, MEMS device is required strongly.
- Especially space and astronautical science area require small and high-performance devices.

Space and astronautical science area is a frontier of MEMS devices and technologies.