Fabrication of HARPSS Single Crystal Silicon Vibrating Ring Gyroscope

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2) Operating Principles of Vibratory Gyroscopes
3) The Vibrating Ring Gyroscope
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5) Fabrication of SCS Vibrating Ring Gyroscopes
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Introduction to Si-Micromachined Gyroscopes

What is a Gyroscope?

A gyroscope is a device that can measure rate or angle of rotation.

Silicon Micromachined Gyroscopes are a class of MEMS devices which are extremely popular in detection of rotational motion.

Advantages of Si-Micromachined Gyroscopes:

1) Reduce the size of the sensors by orders of magnitude
2) Reduce the fabrication costs significantly
3) Allow electronics to be integrated on the same Si Chip

Introduction to Si-Micromachined Gyroscopes

Applications of Si-Micromachined Gyroscopes:

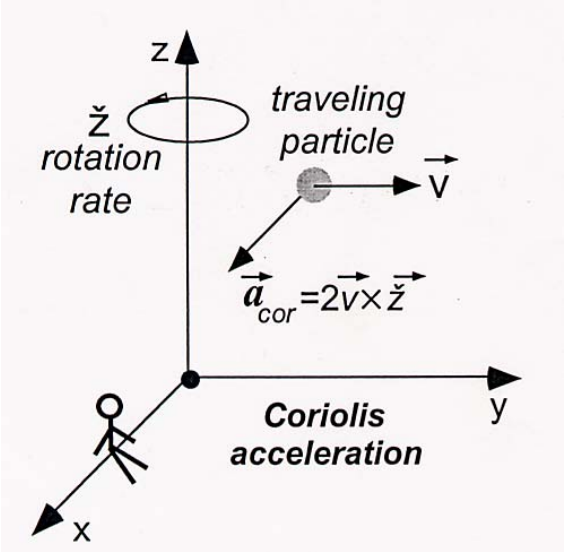
1) Inertial Navigation
   (resolving the heading direction)
2) Automotive Applications
   (traction control, ride stabilization and roll-over detection)
3) Consumer Electronics
   (video camera stabilization, Segway and inertial mouse)
4) Military Applications
   (guidance of missiles and platform stabilization)

Operating Principles of Vibratory Gyroscopes

Vibrating Ring Gyroscopes are a class of devices that use vibrating mechanical elements to sense rotation. They have no rotating parts that require bearings, thereby making them easy to miniaturize and batch fabricate using micromachining techniques.

All vibratory gyroscopes are based on the transfer of energy between two vibration modes of a structure caused by Coriolis acceleration.

Although no real force has been exerted on the particle, to an observer attached to the rotating reference frame an apparent force has resulted which is directly proportional to the rate of the rotation.



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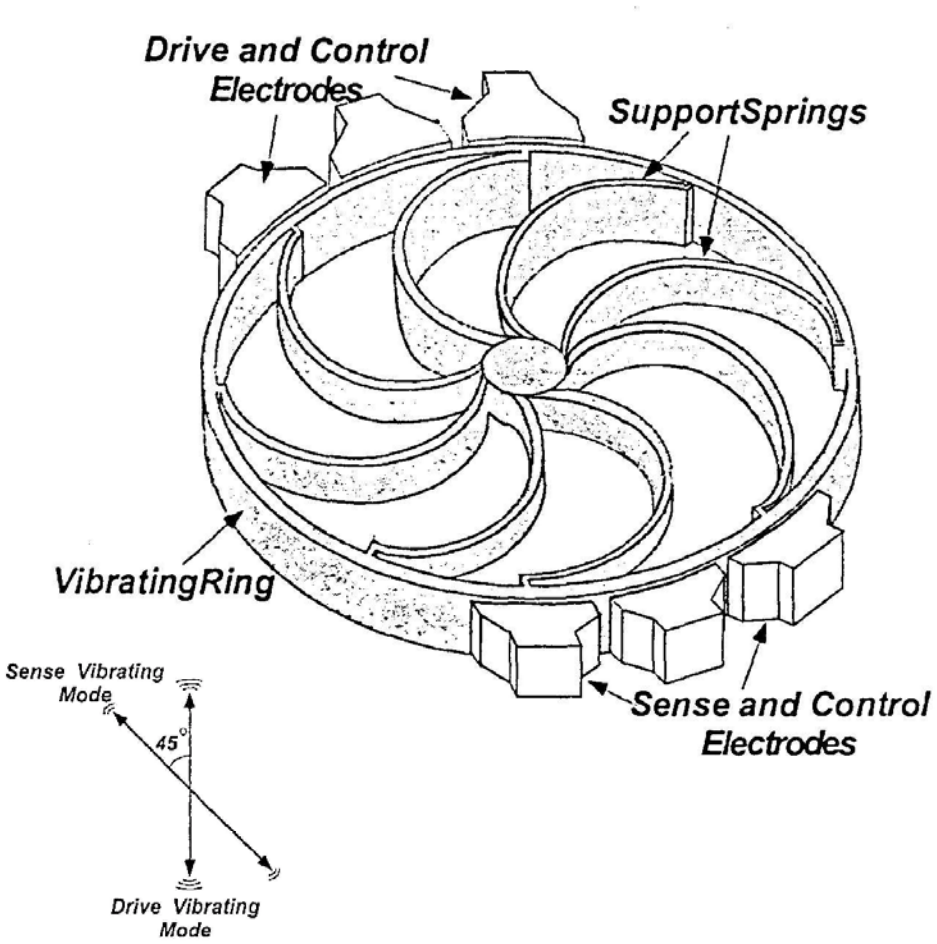
The Vibrating Ring Gyroscope



Consists of ring, semi-circular support springs, and drive, and sense electrodes.

The device is electrostatically vibrated to its primary flexural mode. When device is subjected to rotation around its normal axis, Coriolis force causes energy to be transferred from the primary to the secondary flexural mode (located 45^0 apart from the primary mode). This build-up of amplitude in the secondary mode can capacitatively monitored.

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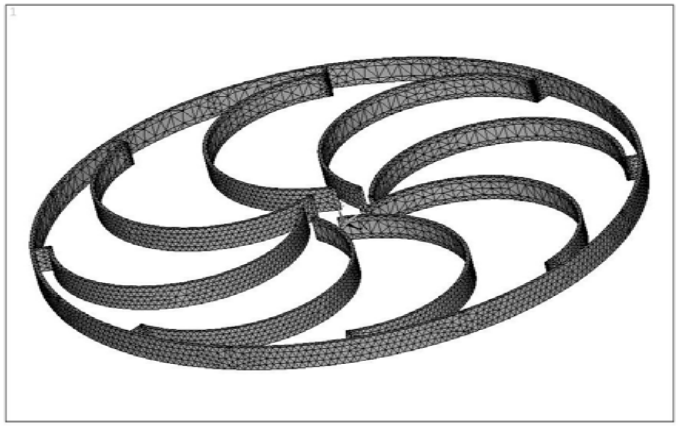
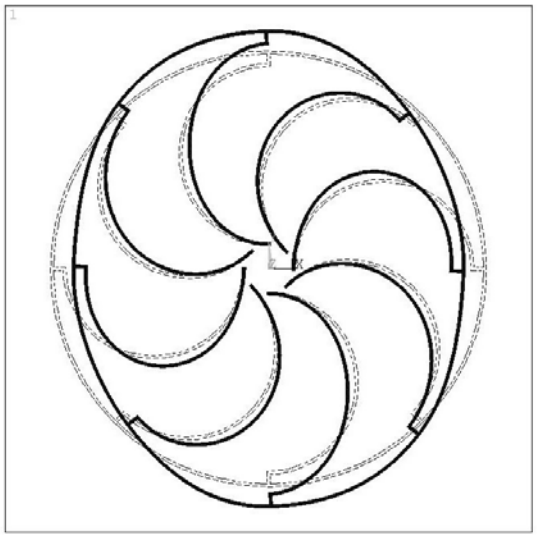
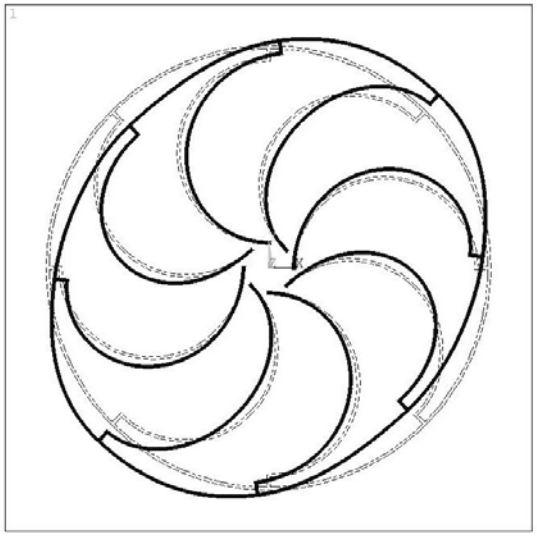
The Vibrating Ring Gyroscope



ANSYS Simulation results showing the two flexural modes of vibration of the Vibrating Ring Gyroscope.



Primary Flexural Mode



Secondary Flexural Mode

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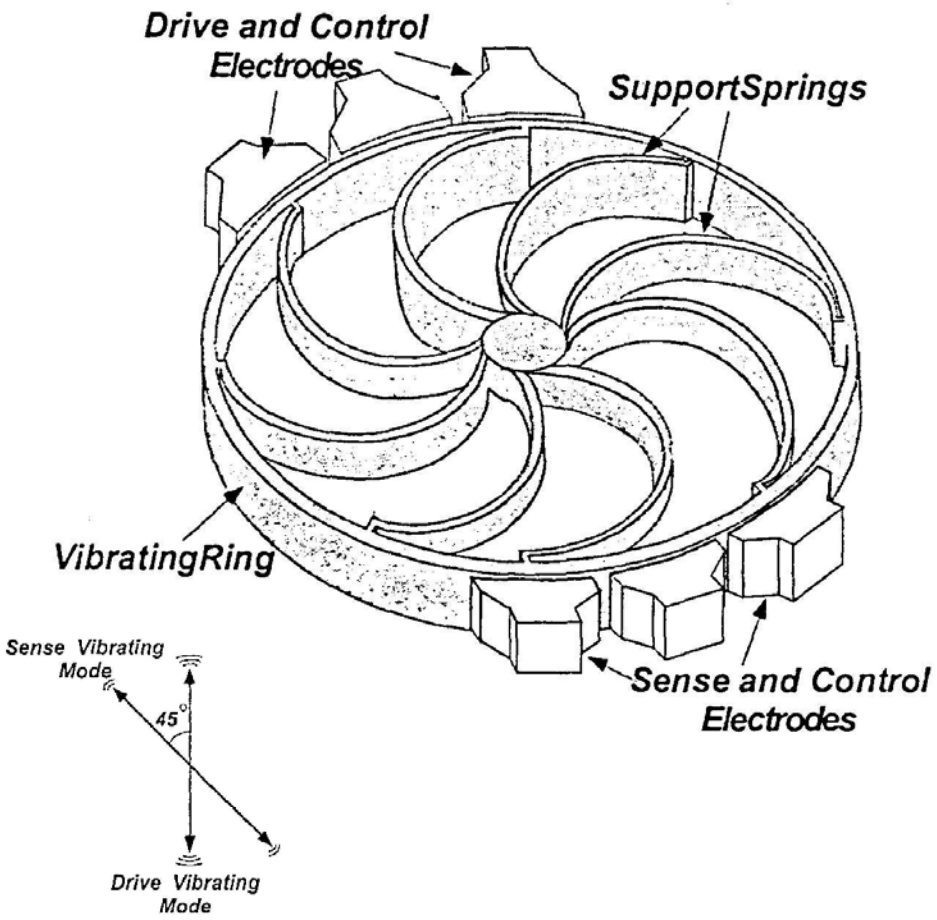
The Vibrating Ring Gyroscope



Important Features:

1) Symmetry of the structure makes it less sensitive to spurious vibrations and temperature variations.
2) Since two flexural modes of the structures with near equal resonant frequency are used to sense rotation, the sensitivity of the sensor is amplified by the quality factor.
3) Any frequency mismatch due to mass or stiffness asymmetries can be compensated using balancing electrodes.

The HARPSS Process

HARPSS - High Aspect Ratio Combined Poly and Single Crystalline Silicon Process

Features:

1) Vertical All Silicon Bulk Micromachining Process

2) Single Crystalline Silicon and Polycrystalline Silicon structures

3) Defined by trenches – high aspect ratio (few μm to 100's of μm)

4) Sacrificial layer defined by oxide thickness (10's of nm to 10's μm)

Fabrication of SCS Vibrating Ring Gyroscope

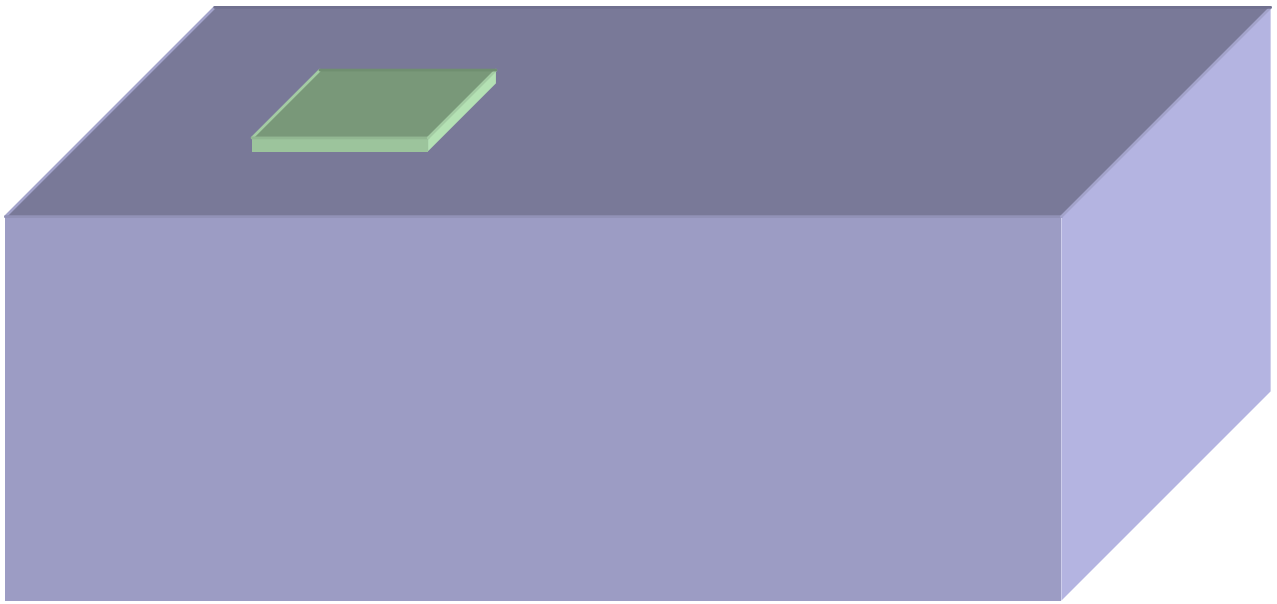
A low resistivity p-type Si wafer is the preferred substrate.

Fabrication of SCS Vibrating Ring Gyroscope

PAD OXIDE:
A 1-1.5 μm thick oxide is grown using Wet Oxidation.

Fabrication of SCS Vibrating Ring Gyroscope

PAD OXIDE: (Mask Step # 1)
Pad isolation is formed.



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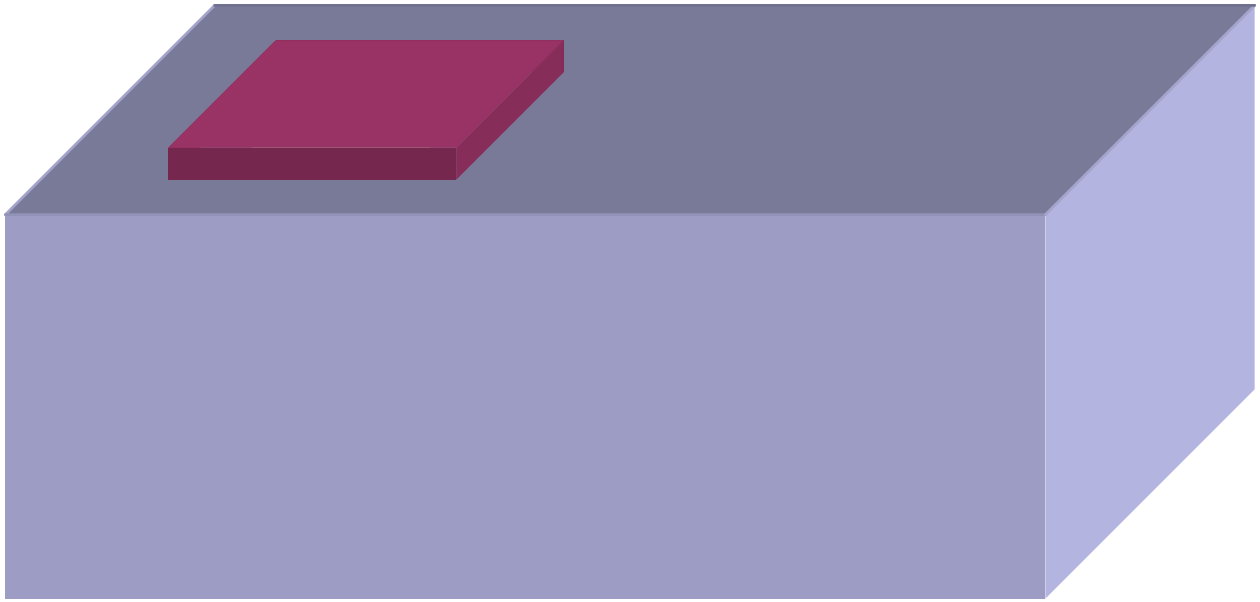
Fabrication of SCS Vibrating Ring Gyroscope

NITRIDE:
A 3000 A thick nitride layer is grown using LPCVD.

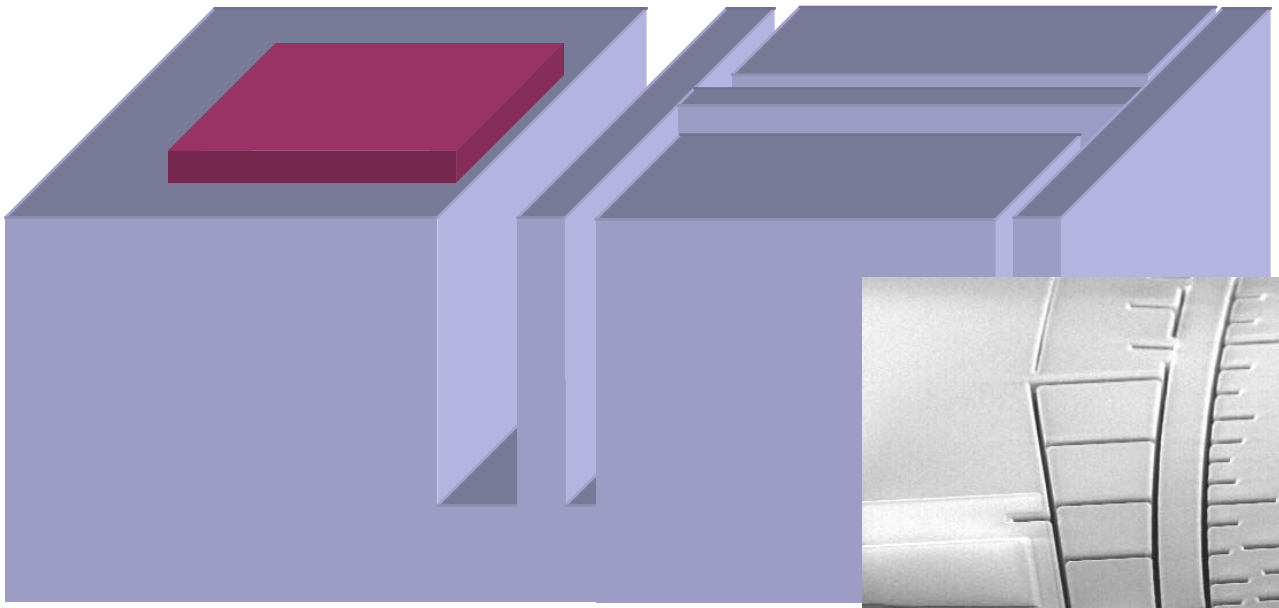
Fabrication of SCS Vibrating Ring Gyroscope

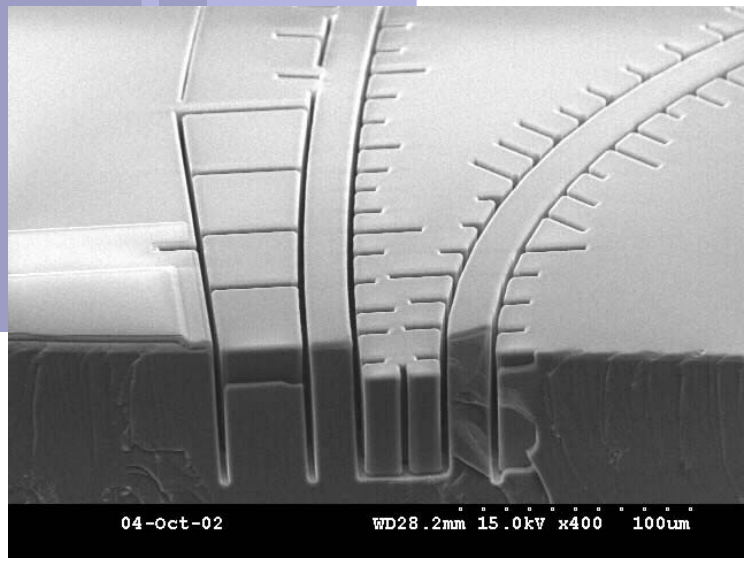
NITRIDE: (Mask Step # 2)
Pad protection is formed.



Fabrication of SCS Vibrating Ring Gyroscope

DRIE: (Mask Step # 3)
Deep Reactive Ion Trench Etching.





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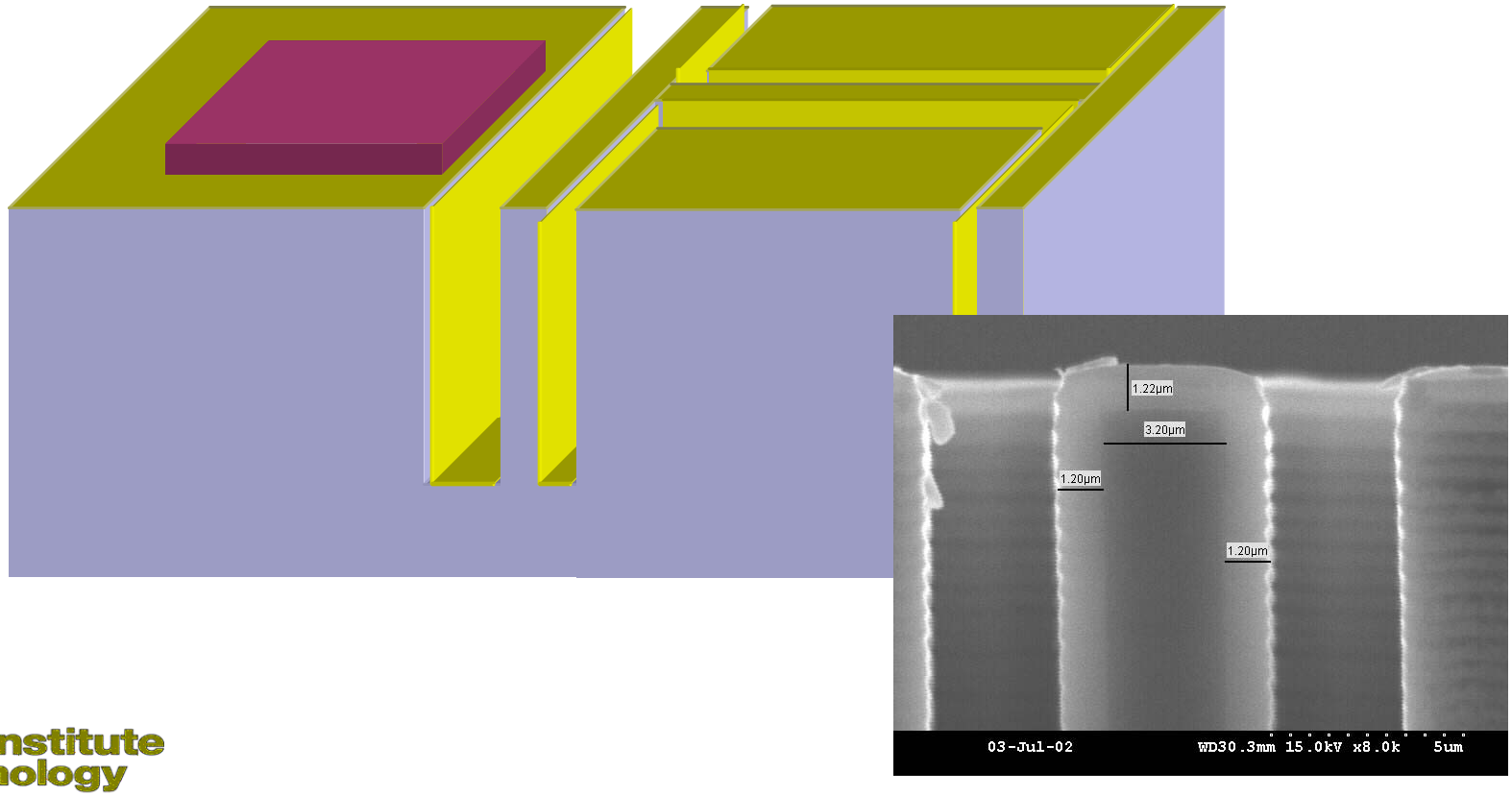
Fabrication of SCS Vibrating Ring Gyroscope

SACRIFICIAL OXIDE:
800nm of sacrificial oxide is deposited using a mixture of Dichlorosilane and Nitrous Oxide in a LPCVD Tube.



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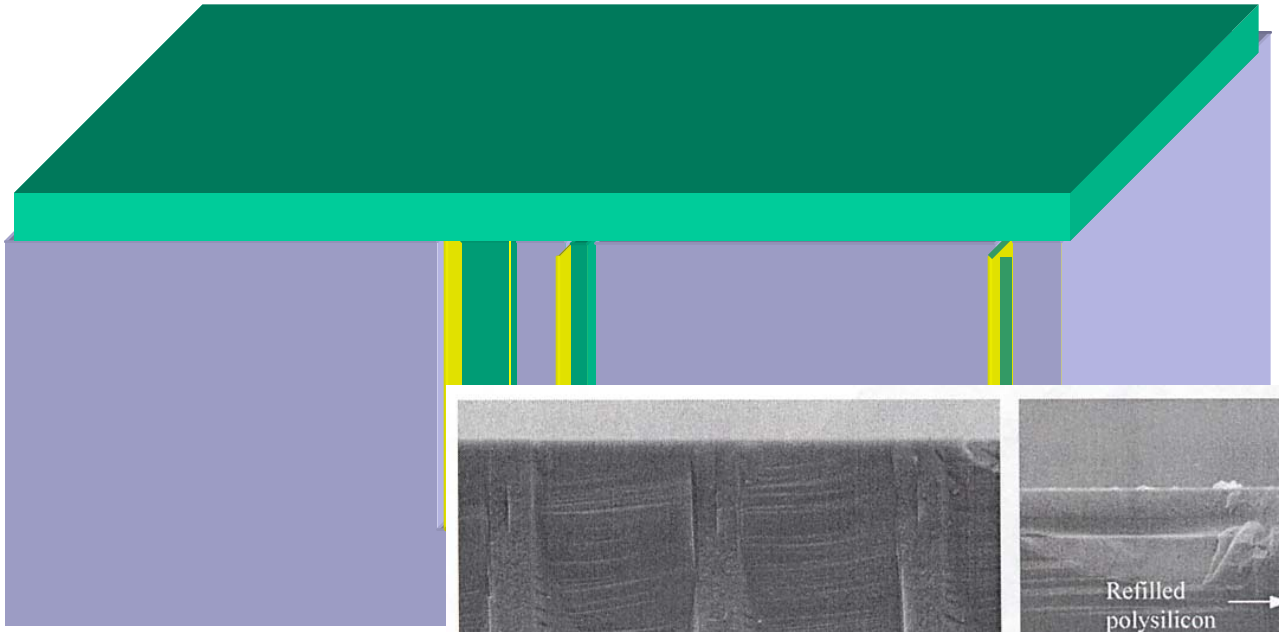
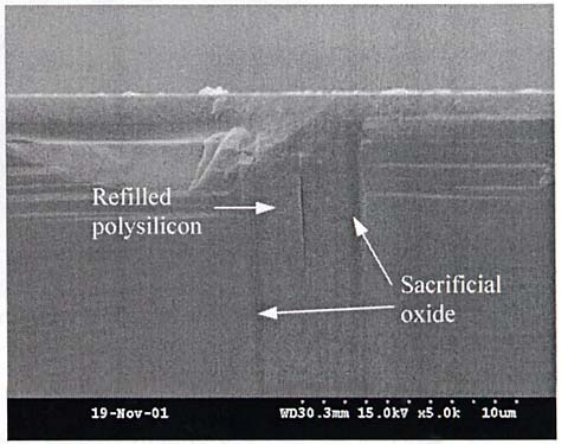
Fabrication of SCS Vibrating Ring Gyroscope

DOPING:
Doping is done to make Polysilicon conductive.
POLYSILICON REFILL:
Approximately 3 μm of Polysilicon is deposited using LPCVD.





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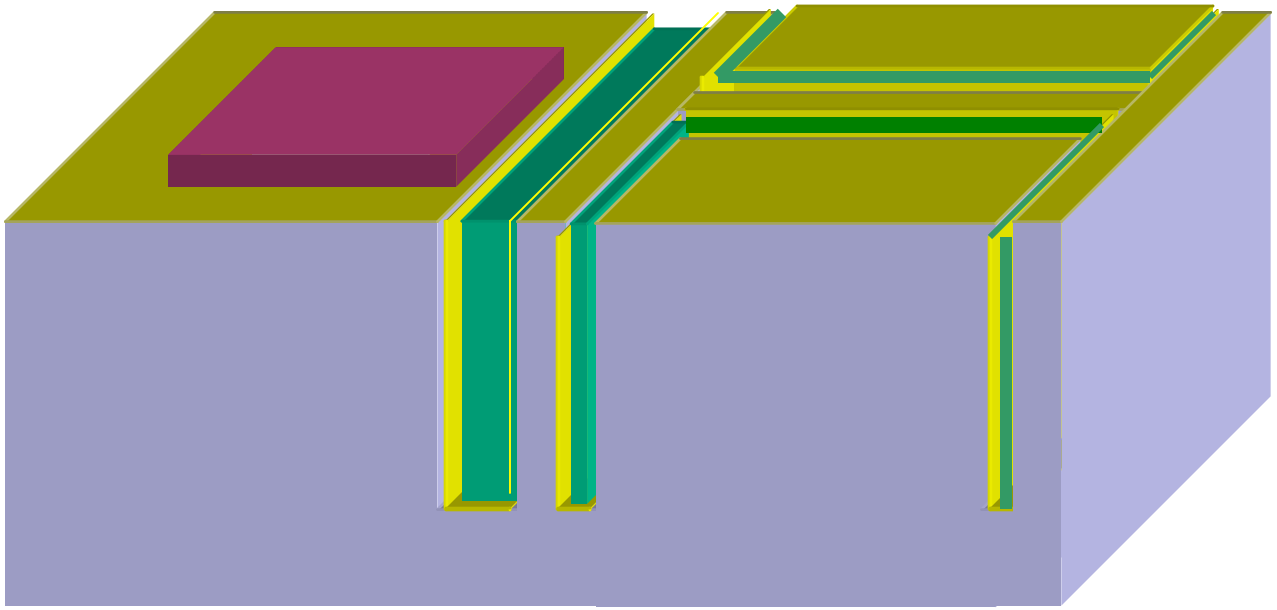
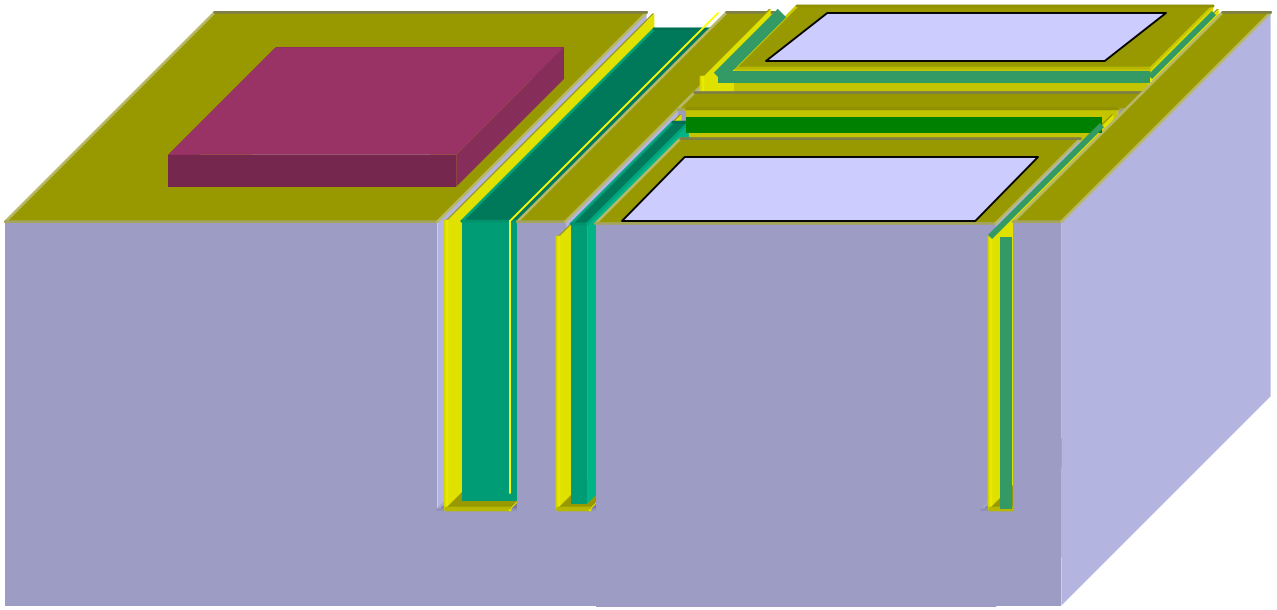
Fabrication of SCS Vibrating Ring Gyroscope

POLYSILICON ETCH BACK:
Polysilicon is etched-back using either ICP or RIE.



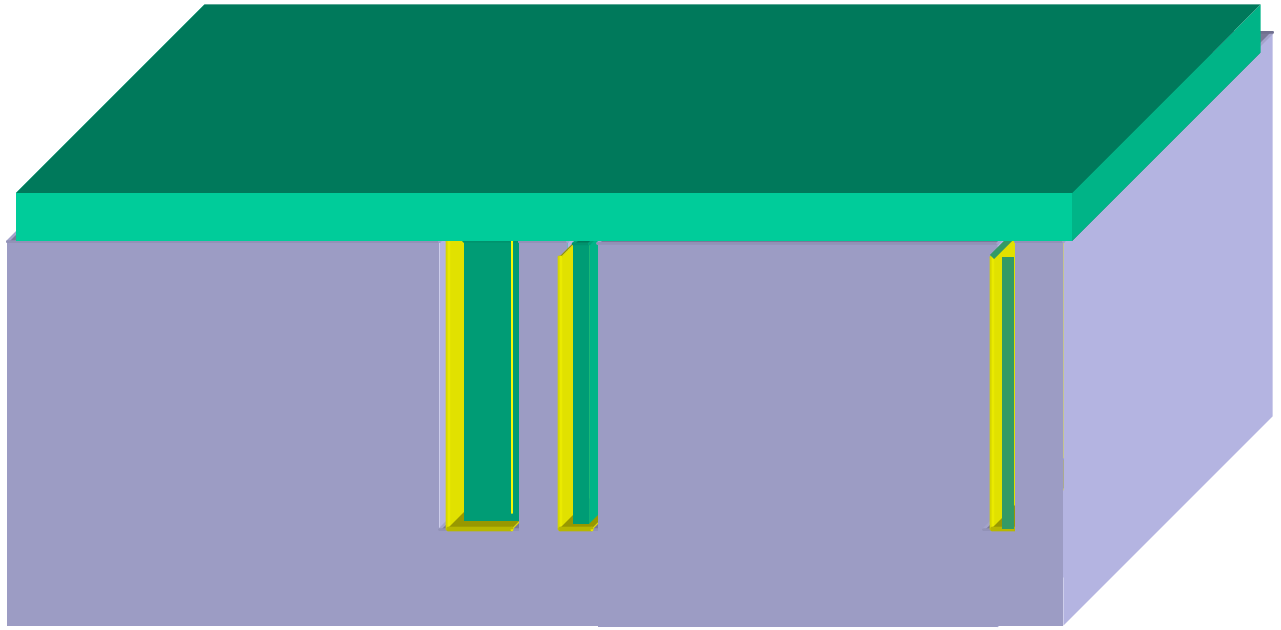
Fabrication of SCS Vibrating Ring Gyroscope

OXIDE PATTERNING: (Mask Step # 4)
Oxide is removed from areas of the release windows using ICP.



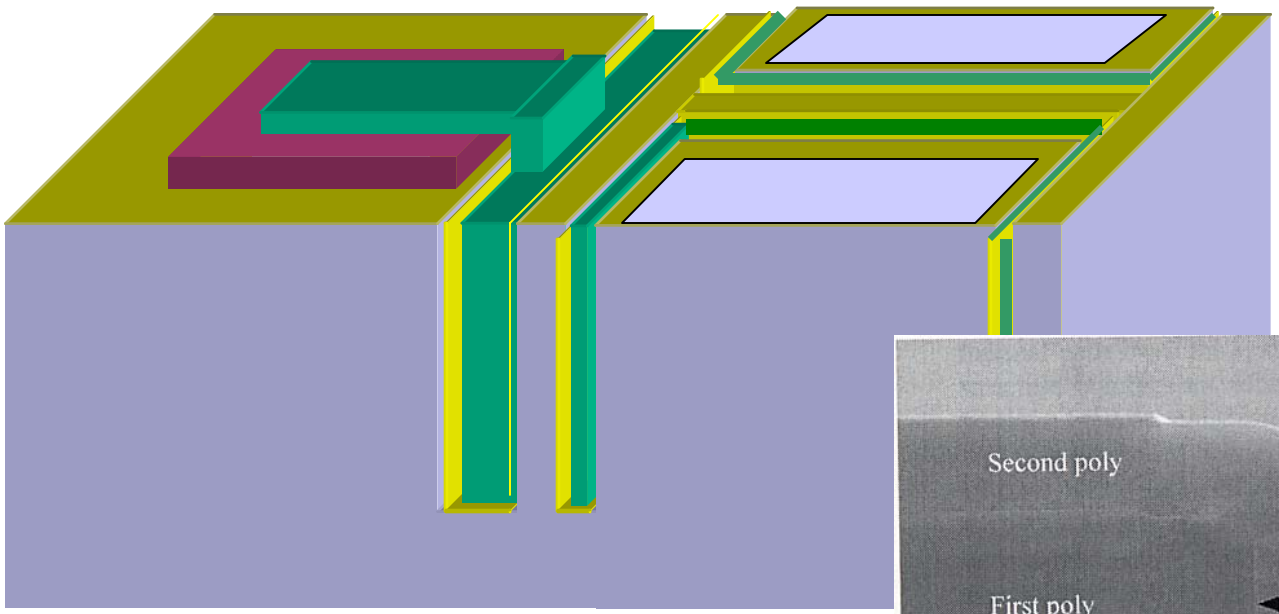
Fabrication of SCS Vibrating Ring Gyroscope

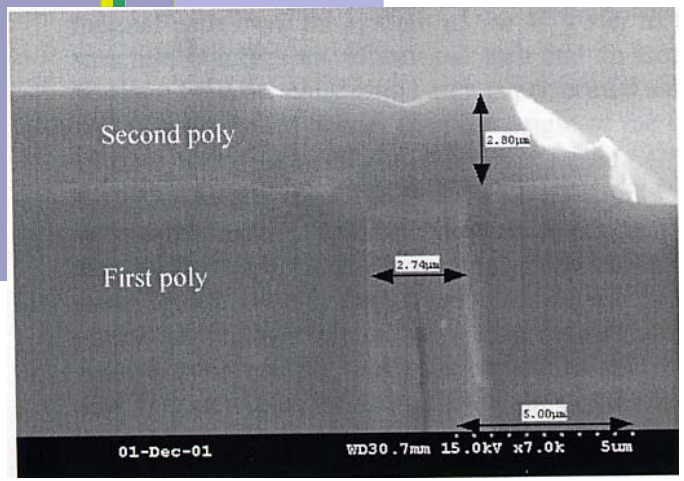
PAD POLYSILICON DEPOSITION:
2 – 3 μm of Polysilicon is deposited
DOPING:
Doping is done to make Polysilicon conductive.



Fabrication of SCS Vibrating Ring Gyroscope

POLYSILICON PAD PATTERNING: (Mask Step # 5)
Polysilicon is etched using ICP/RIE.





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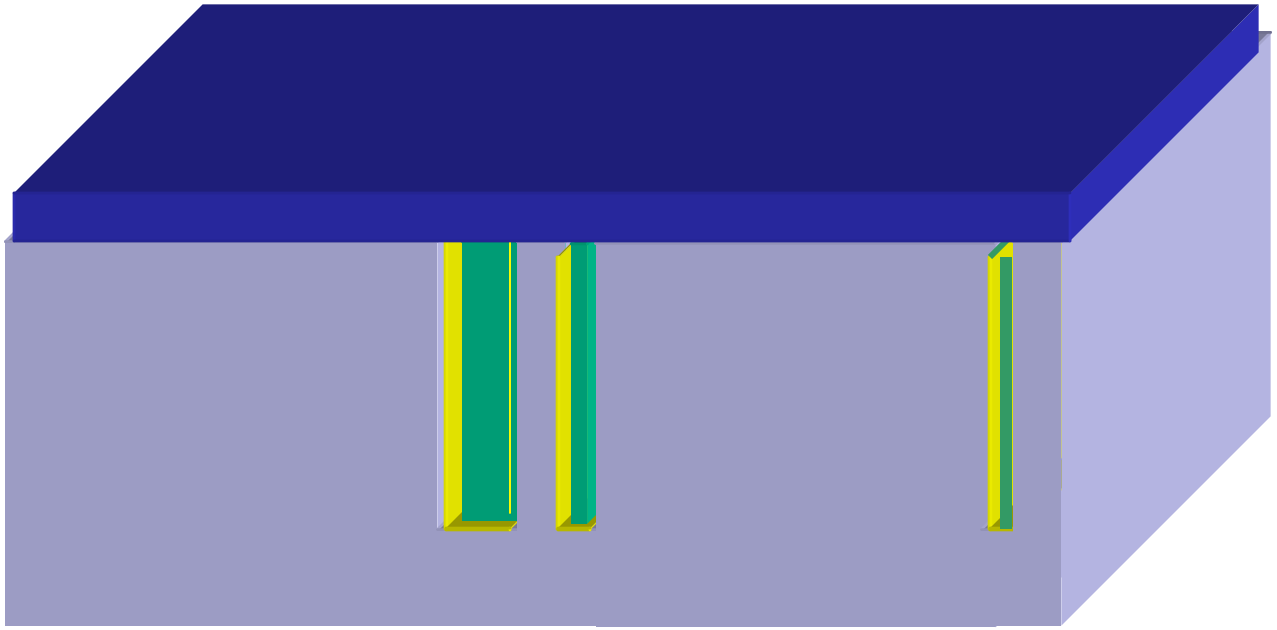
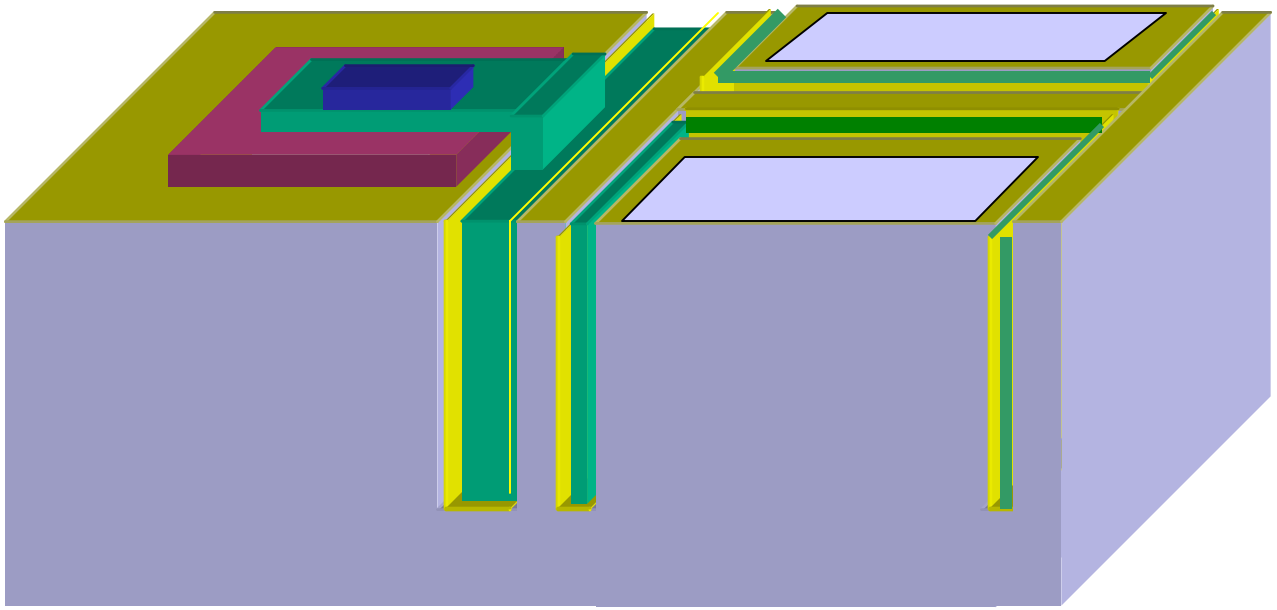
Fabrication of SCS Vibrating Ring Gyroscope

METALLIZATION:
Gold is deposited using E-Beam Evaporator



Fabrication of SCS Vibrating Ring Gyroscope

METAL PAD ISOLATION: (Mask Step # 6)
Metal is removed by process of Lift-Off.



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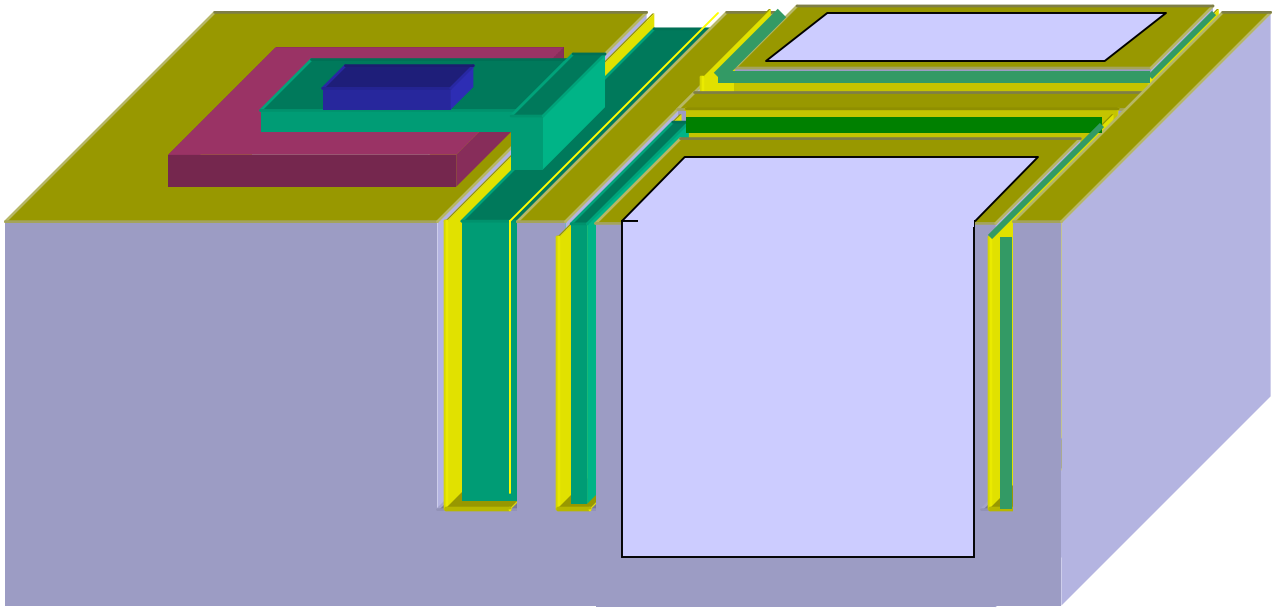
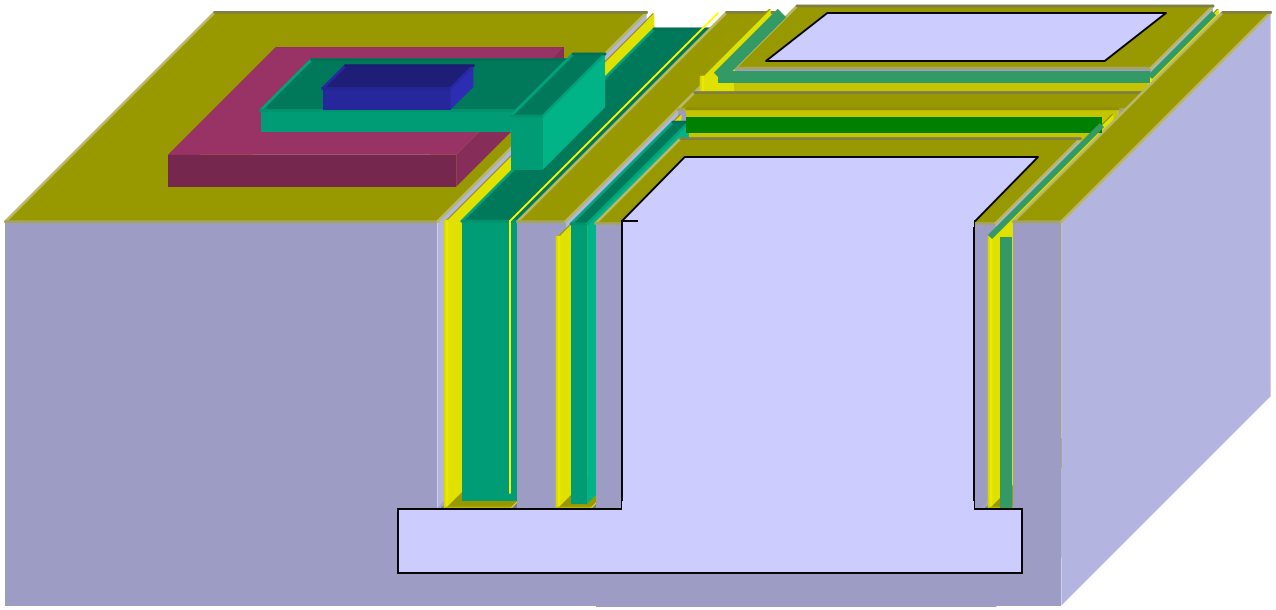
Fabrication of SCS Vibrating Ring Gyroscope

DRL: (Mask Step # 7)
Anisotropic Etch is performed using ICP



Fabrication of SCS Vibrating Ring Gyroscope

DRL:
Isotropic Etch is performed using ICP



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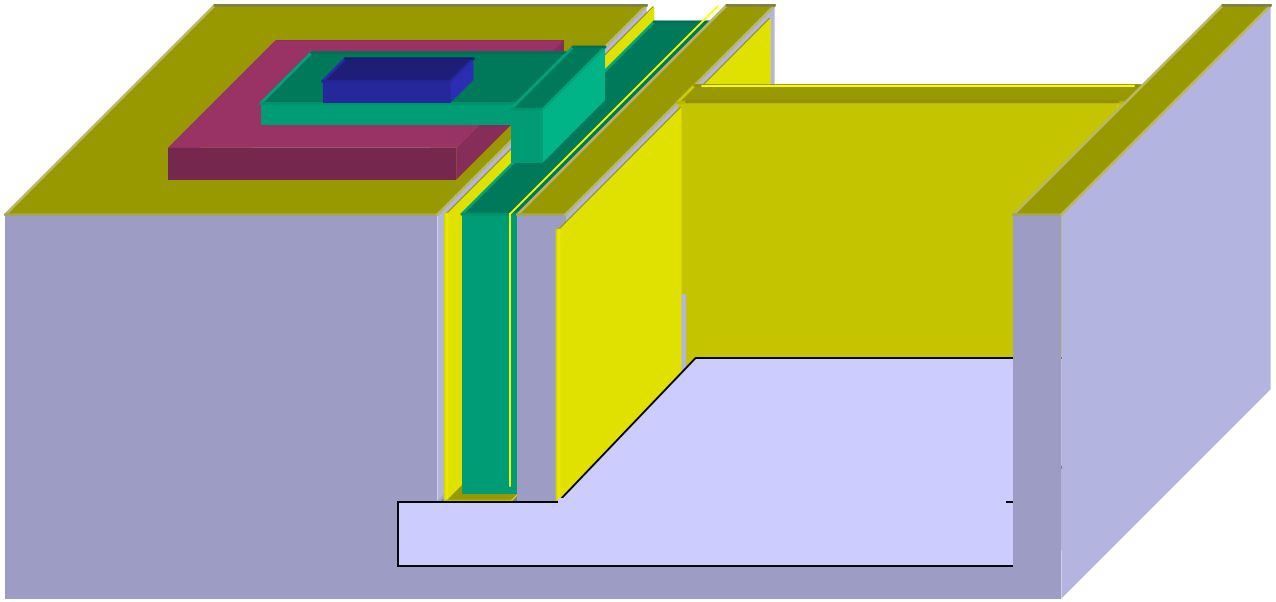
Fabrication of SCS Vibrating Ring Gyroscope

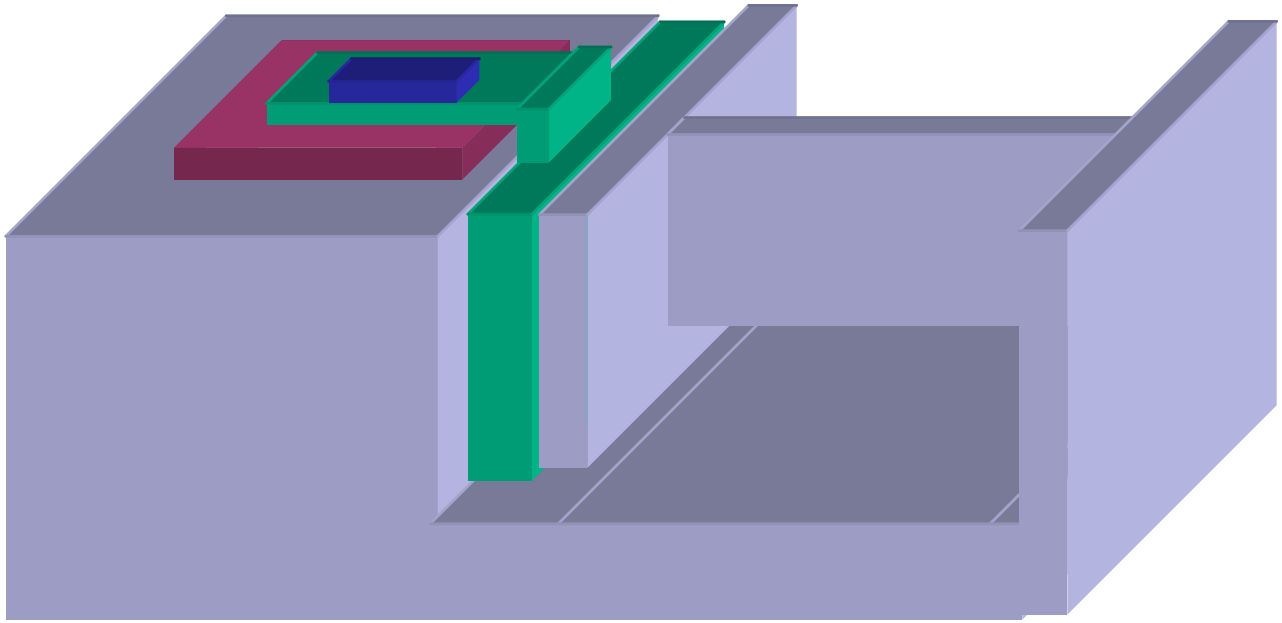
HF Release

Oxide is removed everywhere thereby causing capacitative gaps between poly and single crystal silicon electrodes, and releasing the structure for movement.

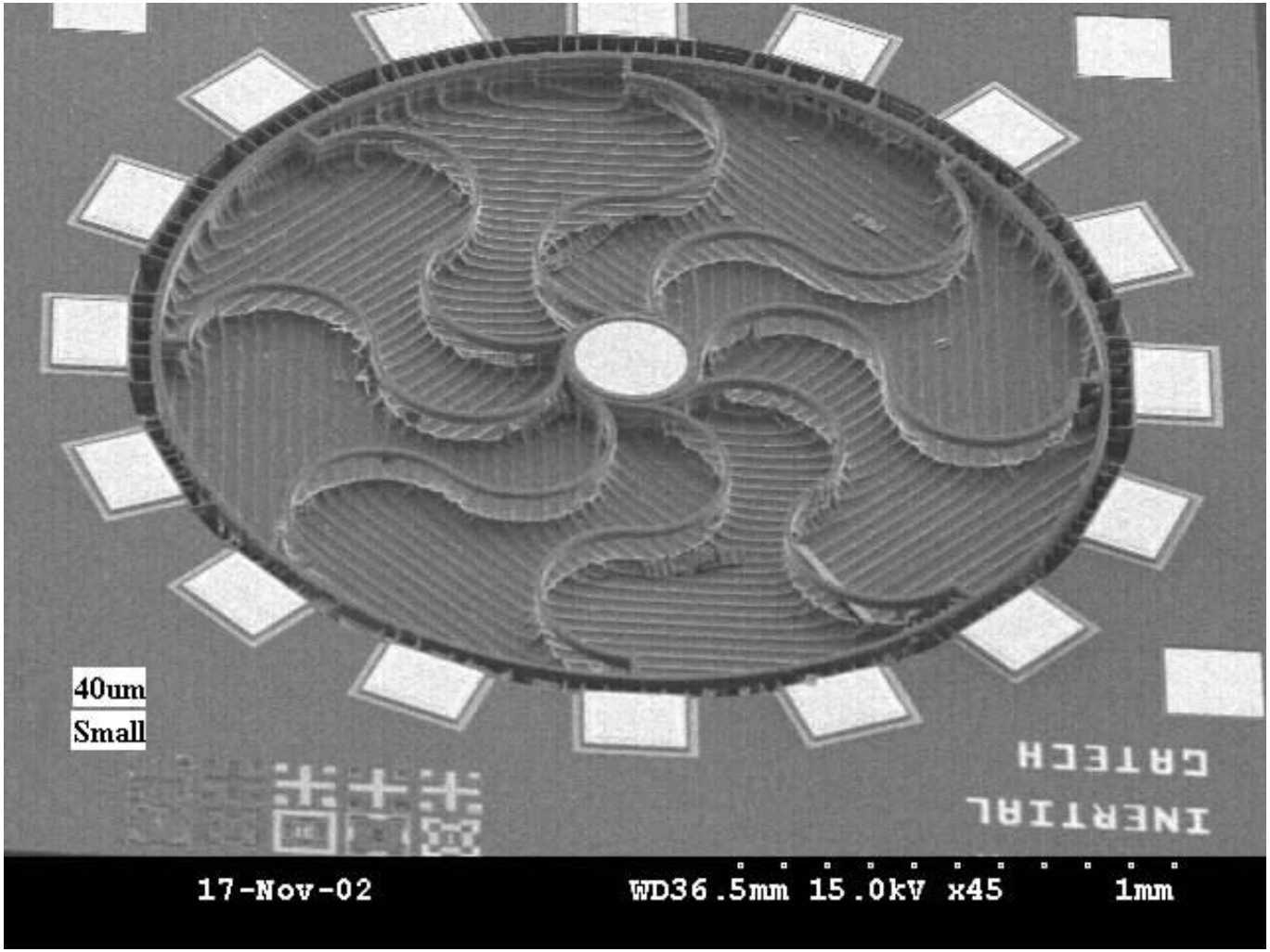


Fabrication of SCS Vibrating Ring Gyroscope

Released Structure !!



SEM Pictures of Fabricated Gyroscope



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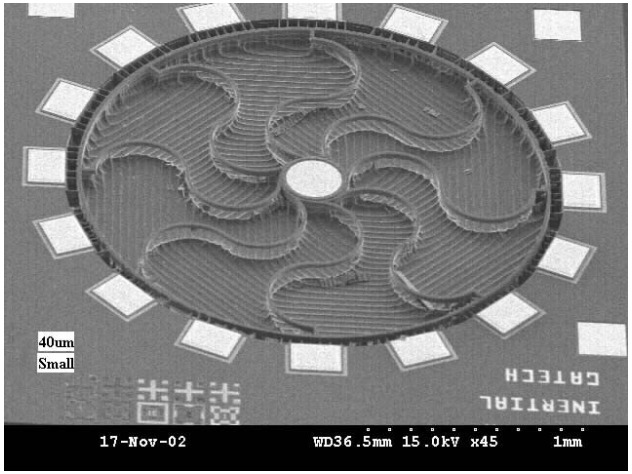
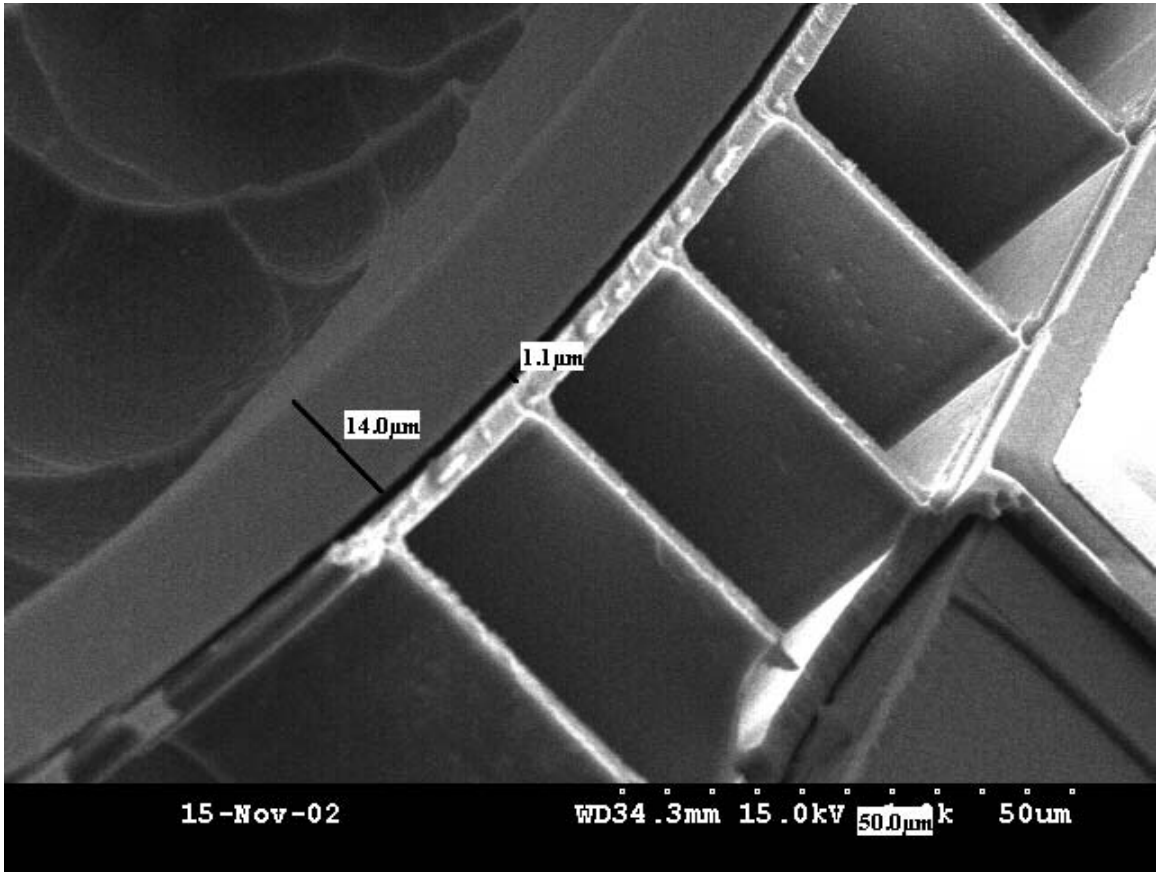
SEM Pictures of Fabricated Gyroscope





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References on Vibrating Ring Gyroscopes

1) F. Ayazi and K. Najafi, "A HARPSS Polysilicon Vibrating Ring Gyroscope" in IEEE/ASME Journal of Microelectromechanical Systems, June 2001, pp. 169-179.
2) F. Ayazi and K. Najafi, "Design and Fabrication of a High-Performance Polysilicon Vibrating Ring Gyroscope," in Proc. IEEE/ASME Micro Electro Mechanical Systems Workshop (MEMS '98), Heidelberg, Germany, Feb. 1998, pp. 621-626.