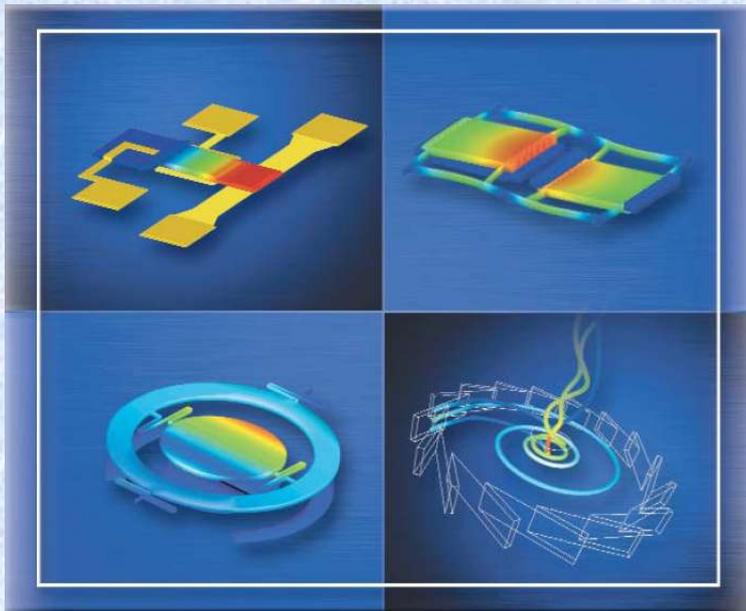


-
-
-
-
-
-
-
-
-
-
-

CAD. Diseño asistido por ordenador



Carmen Aracil Fernández
Antonio Luque Estepa
Dpto. Ingeniería Electrónica

-
-
-
-
-
-
-
-

•
•
•

Índice

- Diseño y simulación
- Software profesional
- Características
- CoventorWare
- ACES

•
•
•

Diseño y simulación

- Fase de diseño fundamental para crear un microsistema.
- Diseño con simulaciones:
 - ahorra lentos y costosos experimentos en el laboratorio
 - reduce el número de pruebas para un prototipo.

-
-
-

Conocimientos previos

- Background del diseño asistido por ordenador de Microelectrónica
 - Reutilización de los módulos fabricados en Microelectrónica.
 - Entorno familiar para los usuarios de Microelectrónica.
- Simulaciones de leyes físicas. Normalmente con efectos acoplados.

CAD para MEMS

- Dibujo de máscaras (layout)
 - MEMSCAP
 - Coventorware.
 - Cadence.
- Simulación de efectos físicos
 - ANSYS Multiphysics. Método de elementos finitos.
 - Coventorware. MEF y otros métodos numéricos
- Simulaciones de procesos concretos

•
•
•

INDICE

- Diseño y simulación
- Software profesional
- Características
- CoventorWare
- ACES

-
-
-

Características

- Bases de datos con propiedades de materiales.
- Simulación de efectos físicos relevantes (análisis térmico, mecánico y estructural, electrostático, electromagnético, fluido, ...).
- Simulación o base de datos con parámetros (limitaciones/tolerancias) de los procesos de fabricación.
- Creación de máscaras.
- Optimización y verificación del diseño.

-
-
-

Índice

- Diseño y simulación
- Software profesional
- Características
- CoventorWare
 - Flujo iterativo
 - Architect
 - Designer
 - Analyzer
 - System Builder
- ACES

CoventorWare

COVENTORWARE MODULES



ARCHITECT™

Design and simulation environment



DESIGNER™

2D layout and 3D modeling



ANALYZER™

Detailed analysis (including FEM) of critical design areas



SYSTEM BUILDER™

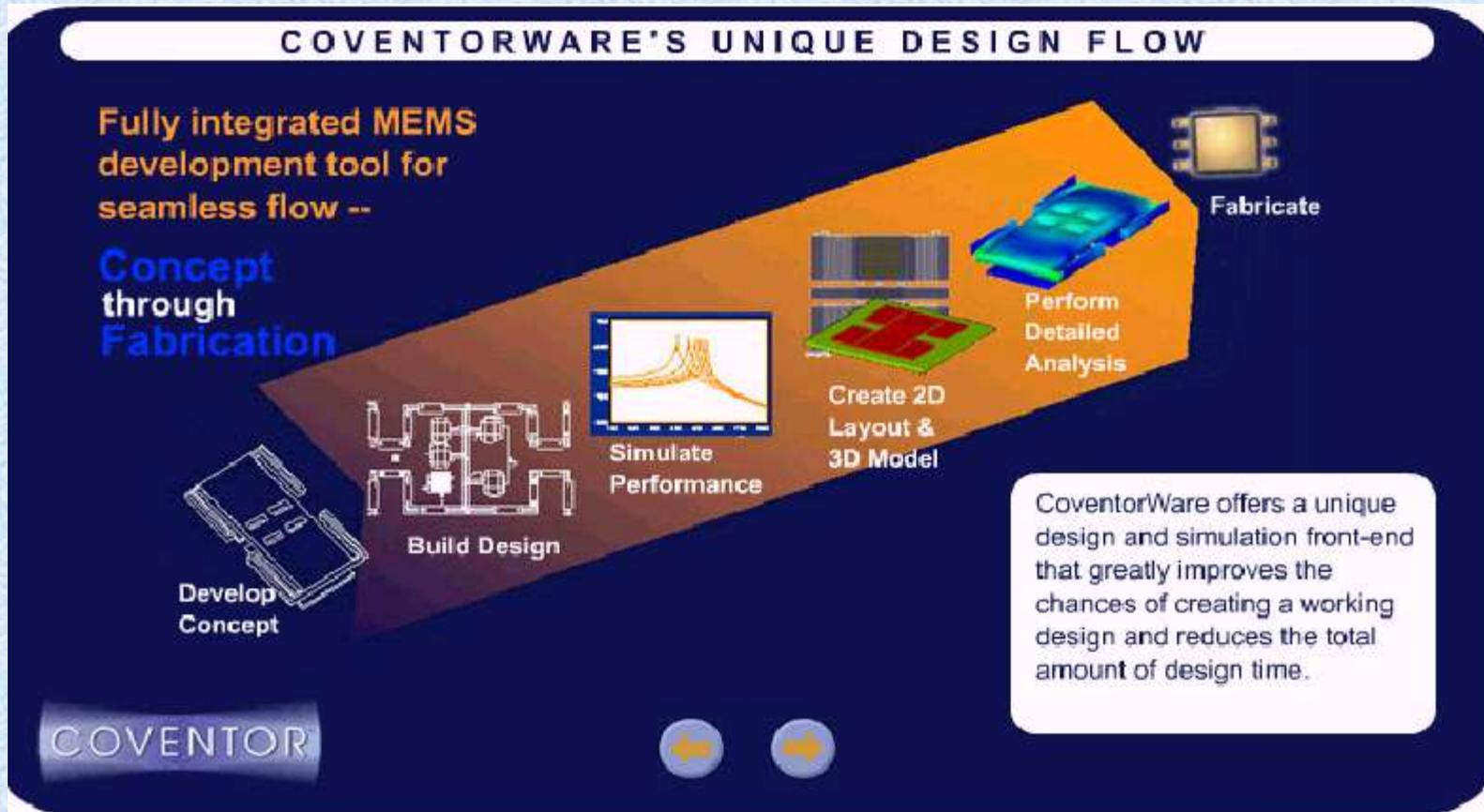
Macro-model extraction

Coventor's comprehensive suite of software tools for MEMS design and analysis interact for design efficiency.

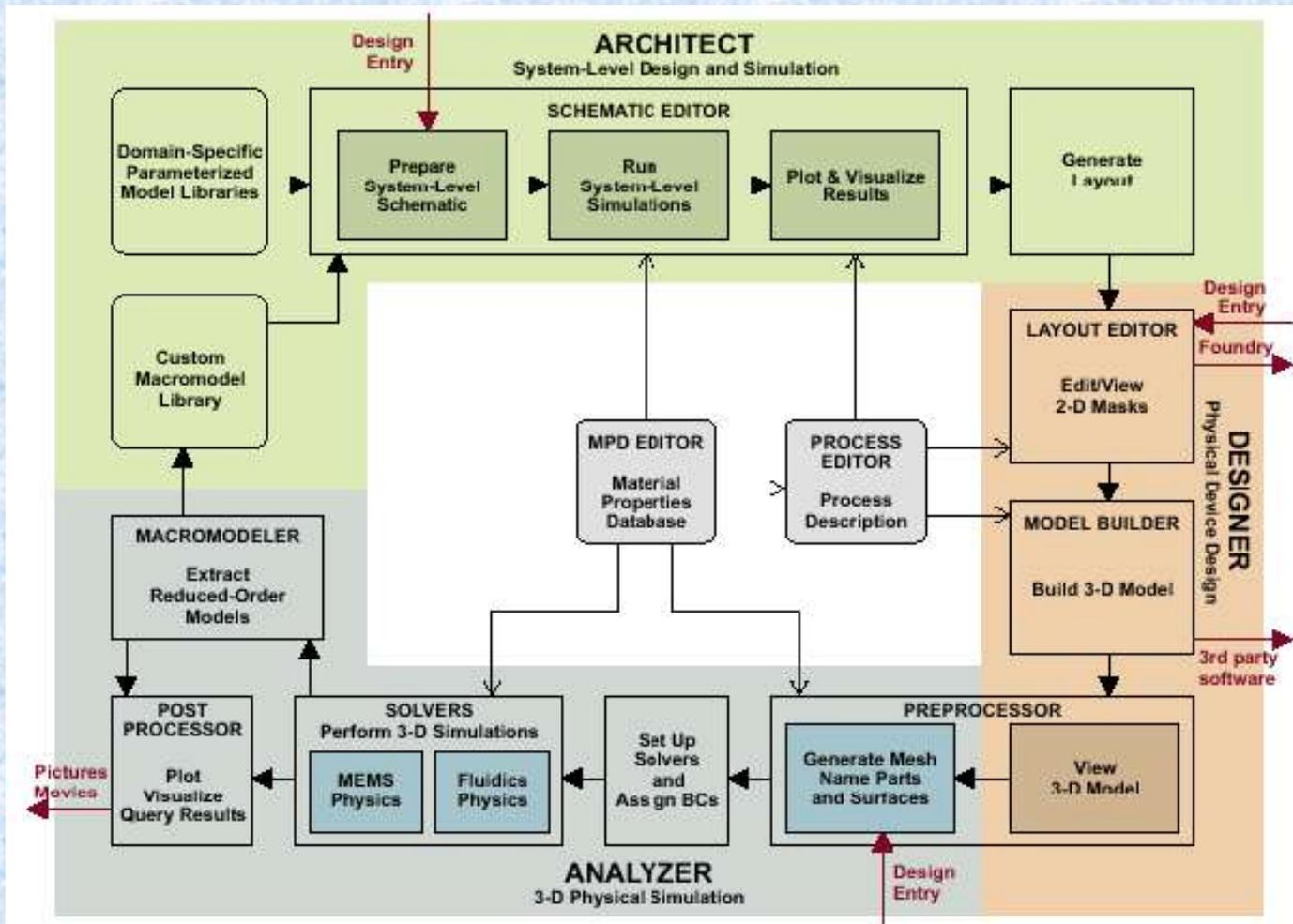
COVENTOR



Diseño MEMS



Flujo iterativo



-
-
-

Módulos comunes

- Editor de procesos
 - Permite crear o editar una descripción del proceso de fabricación.
 - Provee de la información necesaria para crear modelos 3-D.
- Base de datos de propiedades de materiales
 - El software incorpora un fichero por defecto que incluye materiales comúnmente utilizados para la fabricación de MEMS.
 - Se pueden añadir nuevos materiales

-
-
-

Architect (I)

- Simulador a nivel de sistema: basándose en el comportamiento de un dispositivo expresado en un número reducido de ecuaciones.
- Se trabaja con librerías de componentes individuales que se conectan y configuran para resolver la mayoría de problemas de MEMS

Architect (y II)

ARCHITECT SIMULATION CAPABILITIES

ARCHITECT Offers:

Sensitivity analysis

- Design parameters
- Material properties
- Manufacturing process tolerances

Parametric studies

- Actuation configurations, voltages, and performance
- Frequency response

Electromechanical analysis

- Displacement (pull-in) analysis
- Modal analysis
- Transient analysis

MEMS device interaction with

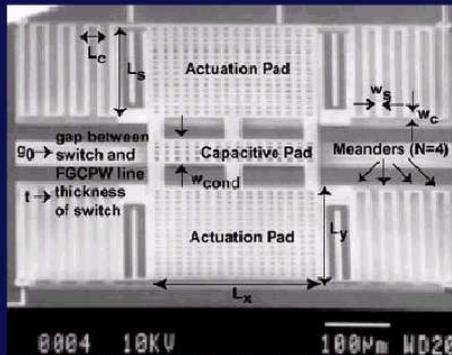
- Surrounding control circuitry
- Packaging
- Other sub-systems

COVENTOR



Ejemplo Architect (I)

ARCHITECT SIMULATION EXAMPLE



Low-Voltage RF MEMS Switch

CoventorWare can be used to design and analyze the mechanical properties of RF and microwave MEMS circuits. This example features a shunt membrane switch circuit over a coplanar waveguide transmission line.

0004 10KV 100µm WD20

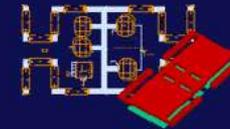
S.P. Pacheco, L. Pal, Karim, and C.T.C. Nguyen, Design of Low Actuation Voltage RF MEMS Switch, Proceedings of the 2000 IEEE IMS, Boston, MA, June 11-16, 2000.

COVENTOR



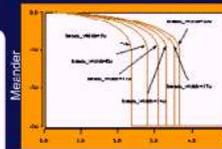
RF SWITCH DESIGN WITH ARCHITECT

Rapid parametric variation helps determine optimum design

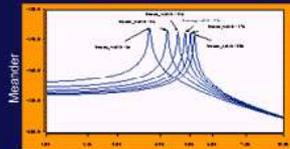


As the meander width is increased the stiffness goes up, thus driving up the natural frequency of the device.

As the number of meanders increases, the pull-in voltage decreases due to the decrease in stiffness.



Pull-in Voltage



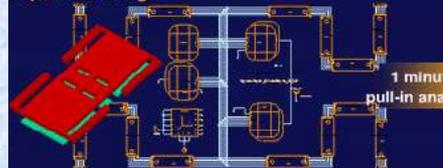
Resonant Frequency

COVENTOR

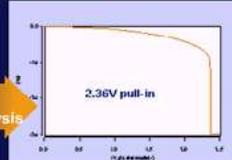


RF SWITCH DESIGN WITH ARCHITECT

Rapid Initial Design

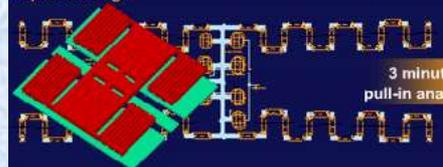


1 minute pull-in analysis

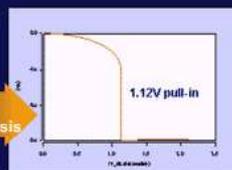


ARCHITECT provides rapid performance simulation and design iteration capability.

Rapid Redesign



3 minute pull-in analysis

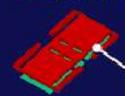


COVENTOR



MANY PARAMETERS ACCESSIBLE FOR SIMULATIONS

RF Switch



3D Model



Schematic

- Layer 1 Parameters**
 - Length
 - Width
 - Thickness
 - Tolerances
 - Young's modulus
 - Poisson's ratio
 - Density
- Other Parameters**
 - Sacrificial layer thickness
 - Electrode thickness
 - Electrode relative permittivity
 - Mirror-electrode height ratio
 - Mirror-electrode width ratio
 - Gimbal-electrode offset
 - Bias voltage
 - Many more
- Layer 2 Parameters**
 - Length
 - Width
 - Thickness
 - Tolerances
 - Young's modulus
 - Poisson's ratio
 - Density

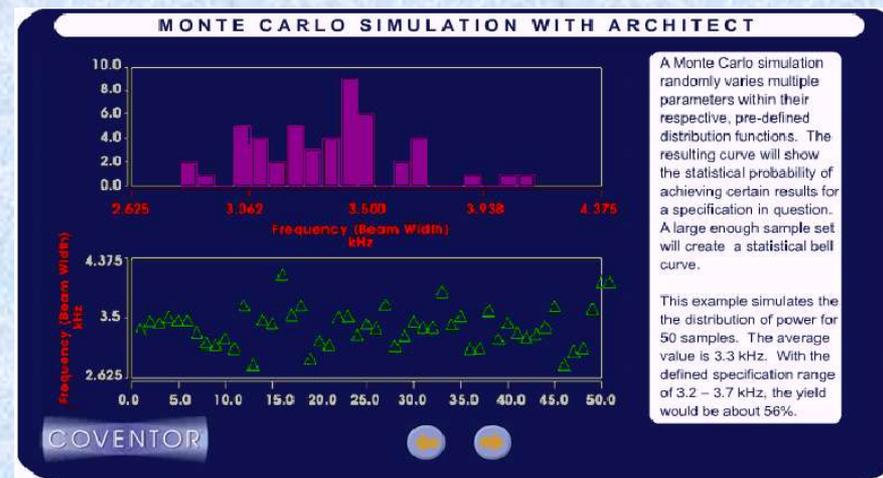
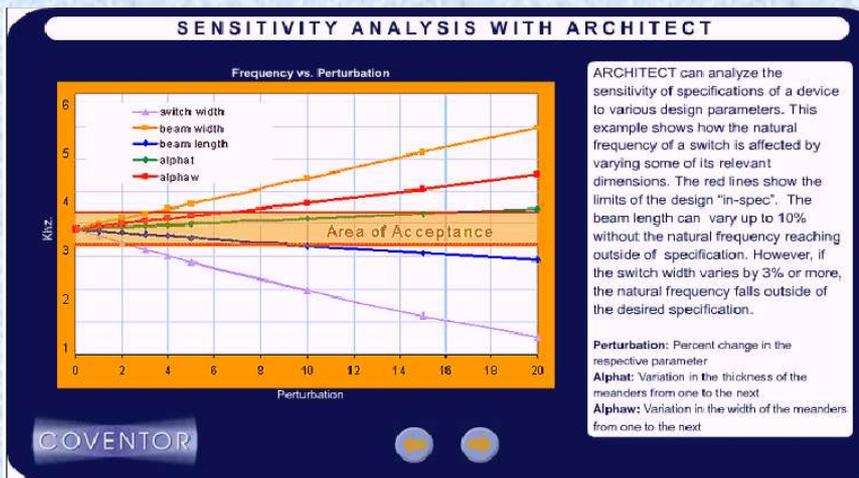
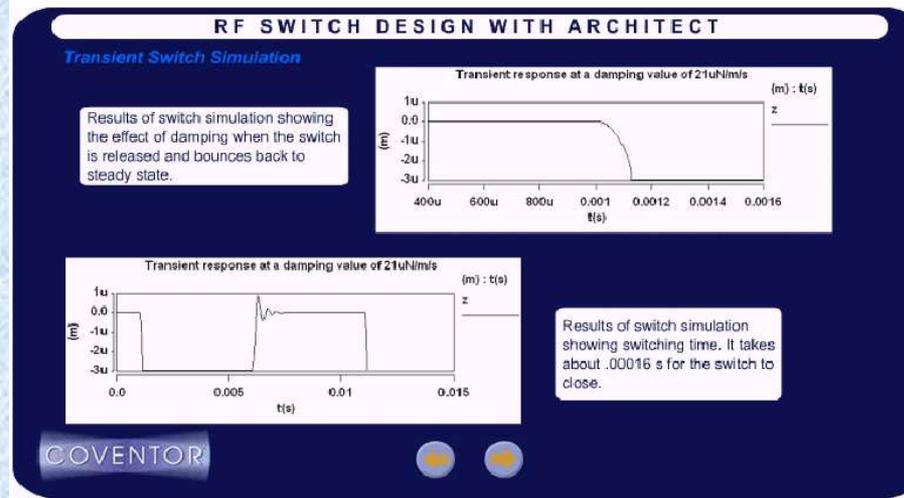
ARCHITECT provides very powerful parametric studies capabilities. Many different parameters can be varied in a short amount of time.

The beam highlighted in the MEMS device is a spring hinge between the switch and its surrounding structure. Varying the parameters of the beam will change the performance of the switch.

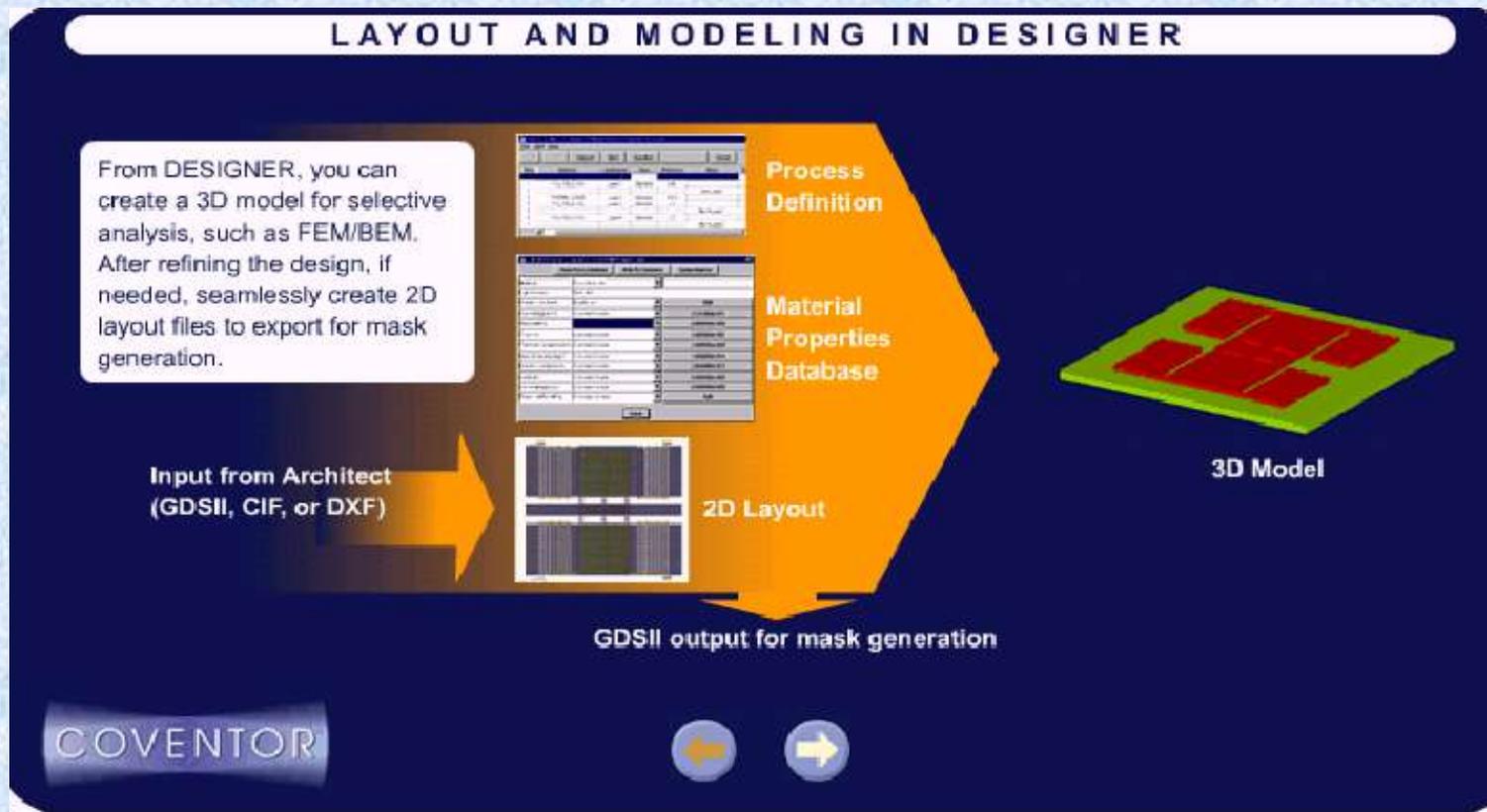
COVENTOR



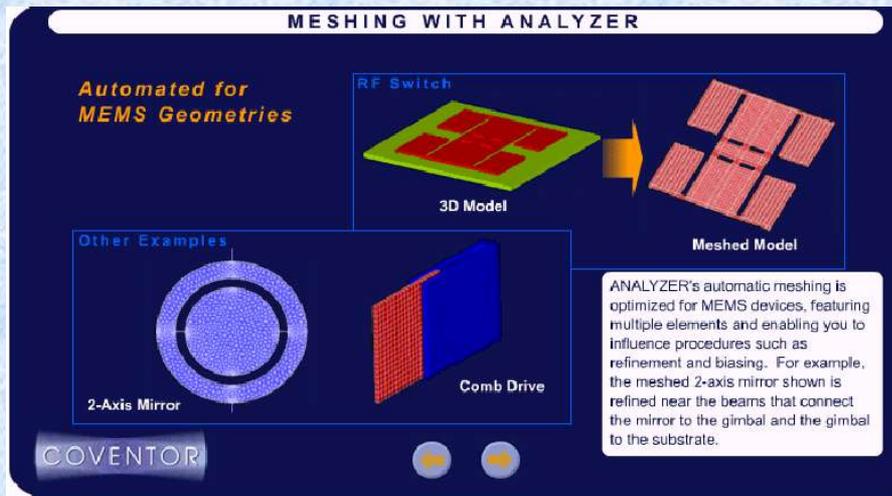
Ejemplo Architect (y II)



Designer



Analyzer (I)



- El mallado automático está optimizado para MEMS caracterizando múltiples elementos y permitiendo influenciar el proceso.

- Puede generar diferentes mallas de elementos finitos para las distintas capas del MEM.

Simuladores disponibles (I)

- MemElectro (electrostática)
- MemMech (termo-mecánico, estructural)
- CoSolve-EM (electro-mecánico)
- MemPZE (piezoeléctrico)
- DampingMM (rozamiento y elasticidad)
- MemETherm (dilatación térmica)
- MemPZR (piezorresistencia)
- MemHenry (inductancia)
- MemOptics (difracción óptica)

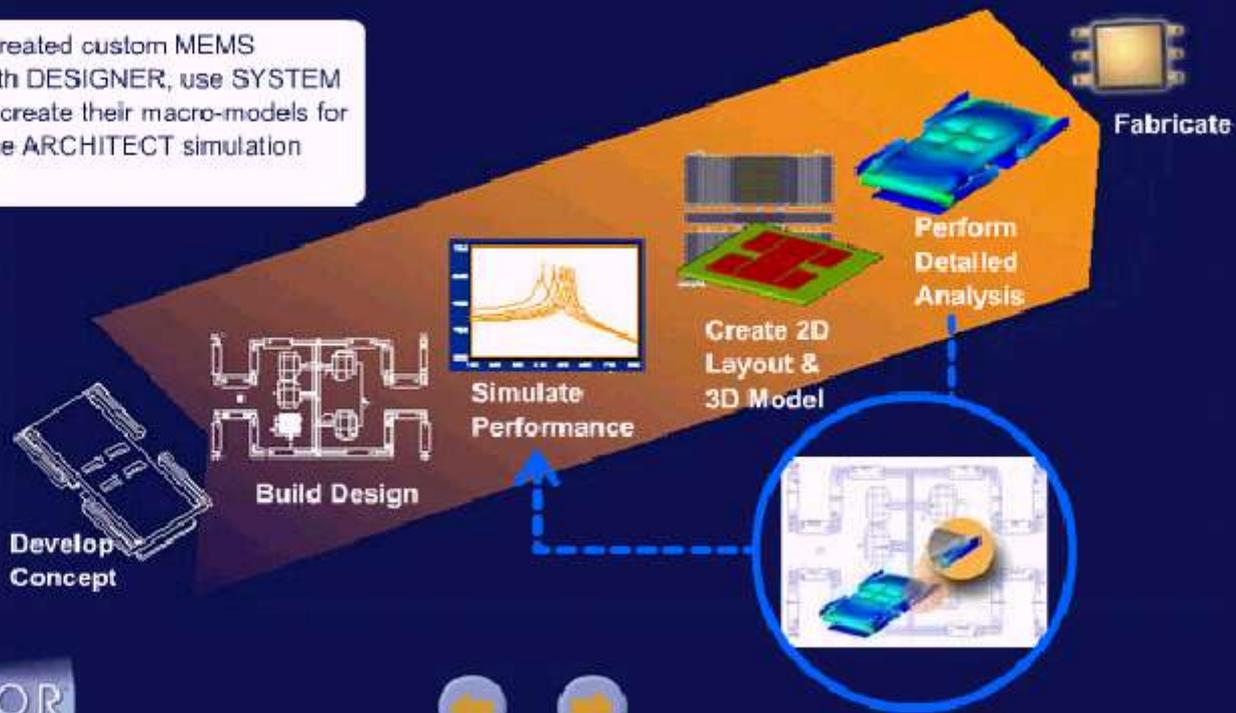
Simuladores disponibles (II)

- SpringMM (muelles)
- MemPackage (efectos del encapsulado)
- MemCFD (fluidodinámica)
- FSI (interacción fluido-estructura)
- NetFlow (transporte en diversos flujos)
- SwitchSim (flujo con campo eléctrico pulsado)
- ReactSim (reacción química)
- DropSim (formación de gotas)

Builder

CREATE MACRO-MODELS WITH SYSTEM BUILDER

If you have created custom MEMS structures with DESIGNER, use SYSTEM BUILDER to create their macro-models for export into the ARCHITECT simulation environment.



•
•
•

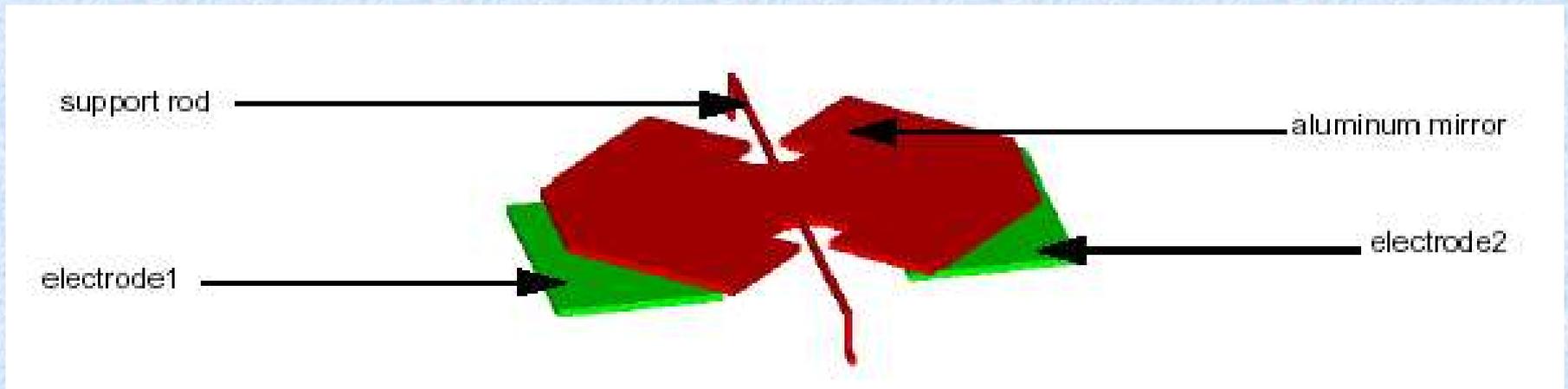
Ejemplo de uso de Coventorware

- Diseño y simulación de un microespejo
- Proceso de fabricación
- Máscaras
- Simulación del comportamiento
- Efectos físicos acoplados

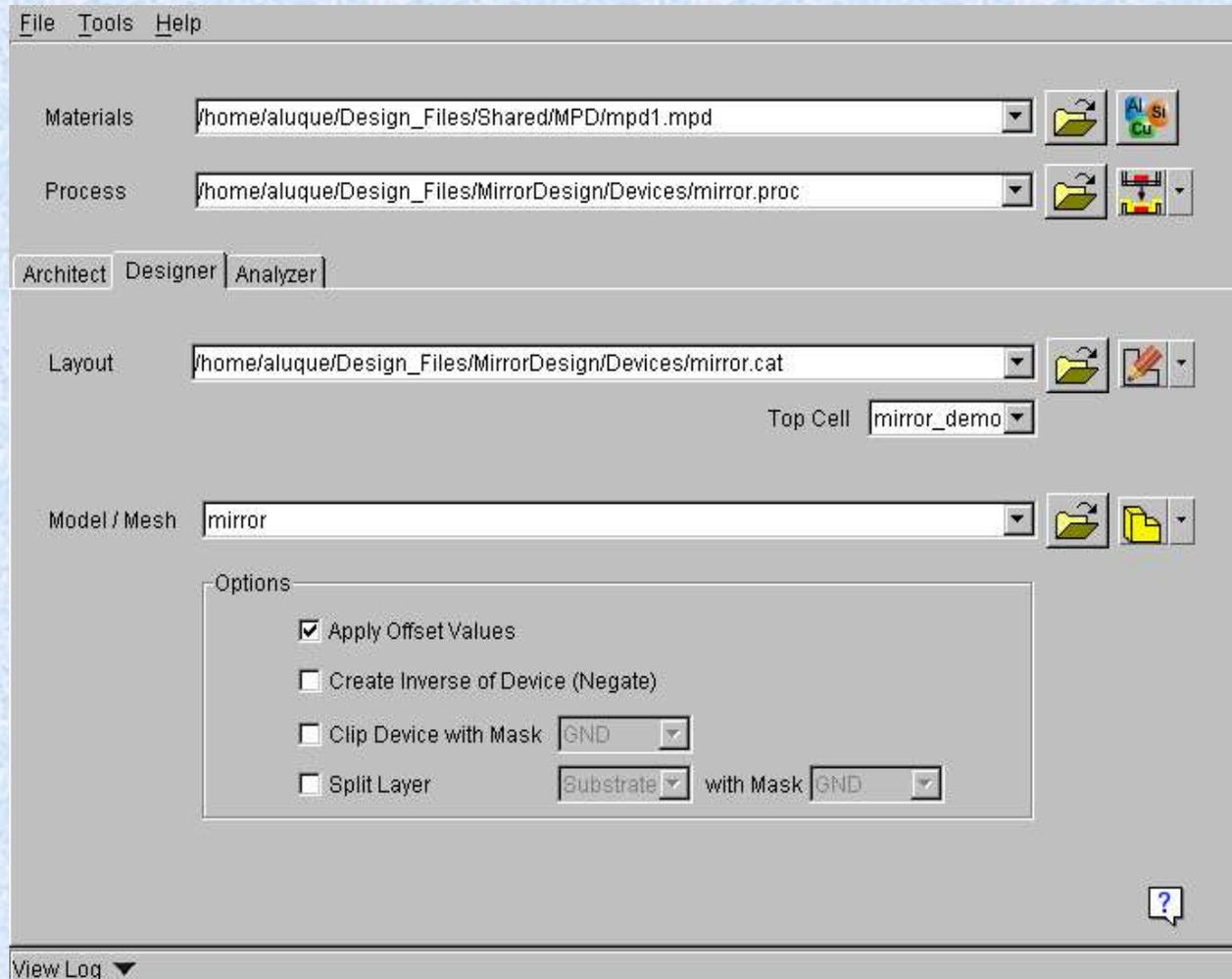
-
-
-

Microespejo

- Conmutador óptico, entre otras aplicaciones
- Actuación electrostática



Inicio de Coventorware



BD de materiales

Edit Materials in /home/aluque/Design_Files/Shared/MPD/mpdL.mpd

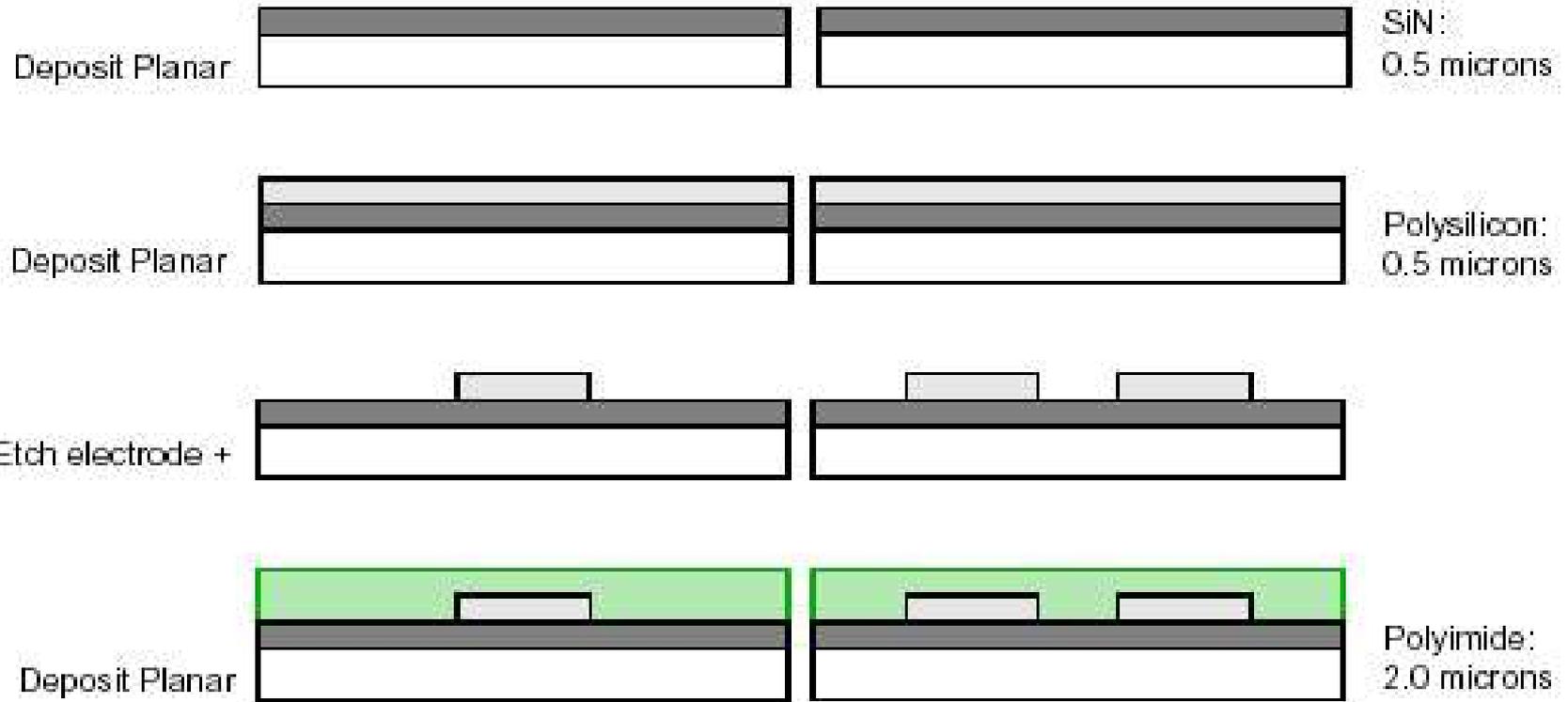
New Material Import Material Copy Material Delete Material

Material	SILICON	
Fab Process	Substrate	
Elastic Constants	Elastic-Iso	Edit
Density(kg/um ³)	Constant-Scalar	2.500000e-15
Stress(MPa)	Constant-Scalar	0.000000e+00
TCE(1/K)	Constant-Scalar	2.500000e-06
ThermalCond(pW/umK)	Constant-Scalar	1.480000e+08
SpecificHeat(pJ/kgK)	Constant-Scalar	7.120000e+14
ElectricCond(pS/um)	Constant-Scalar	0.000000e+00
Dielectric	Constant-Scalar	1.190000e+01
Viscosity(kg/um/s)	Constant-Scalar	0.000000e+00
PiezoResistiveCoeffs(1/MPa)	Constant_Scalar	Edit

Close ?

-
-
-

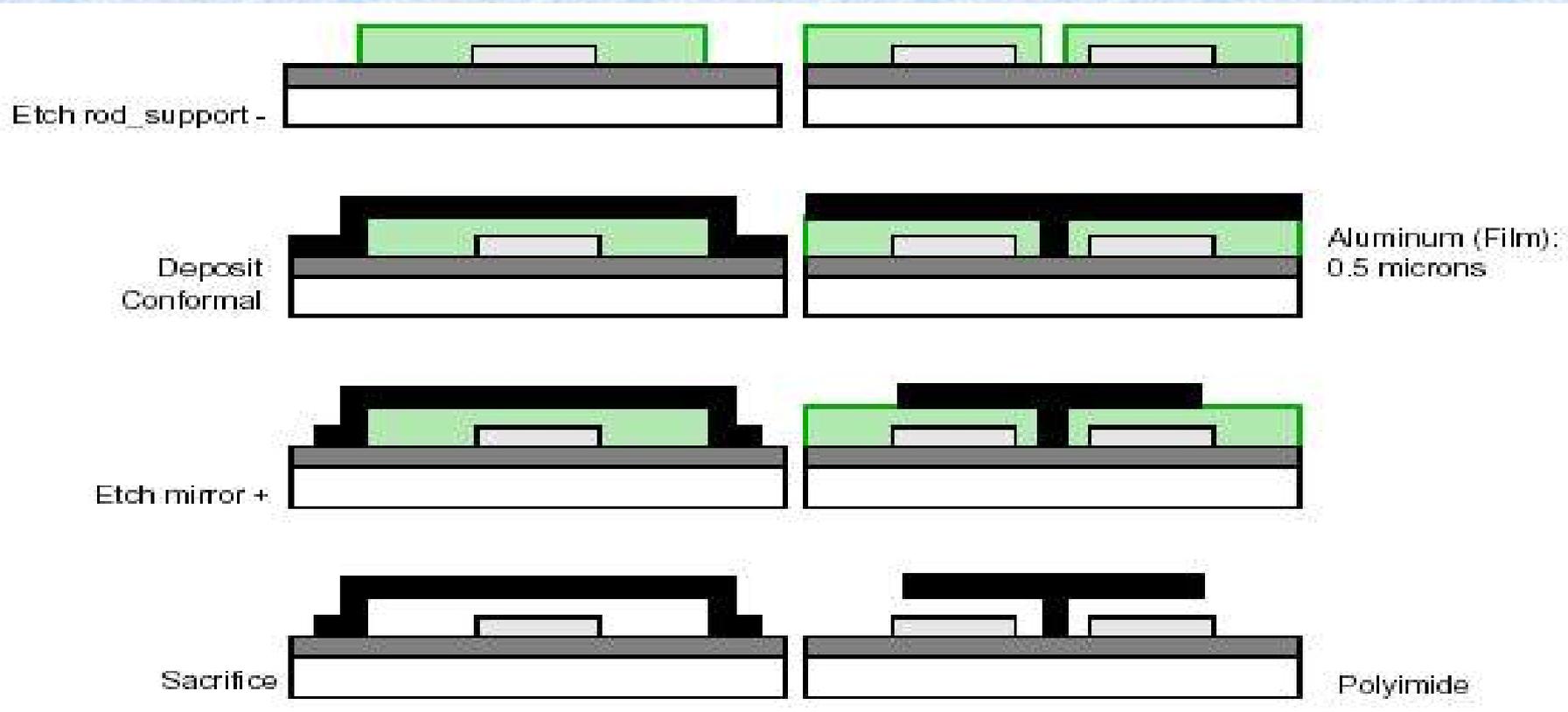
Proceso de fabricación I



-
-
-
-
-
-
-
-
-

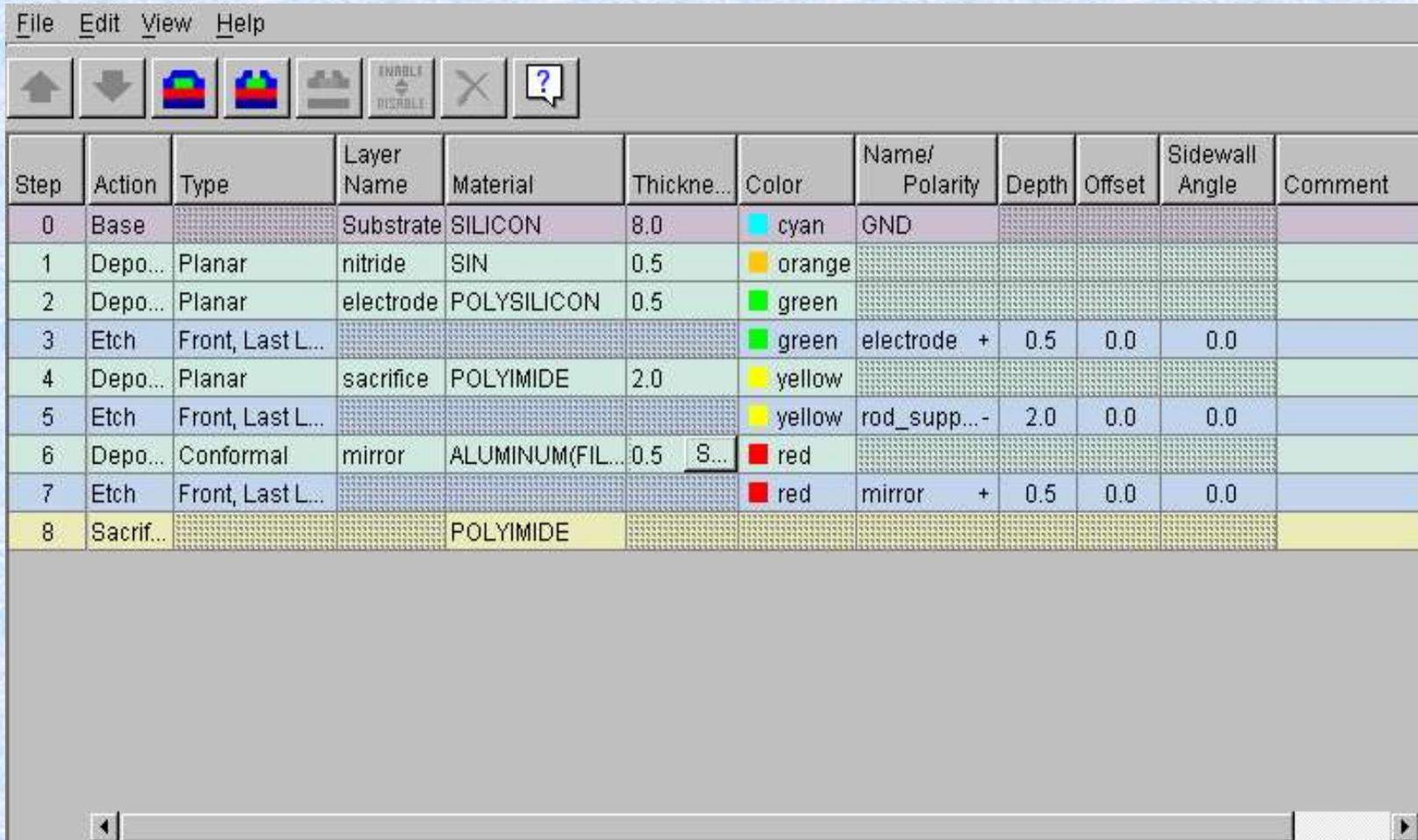
-
-
-

Proceso de fabricación II



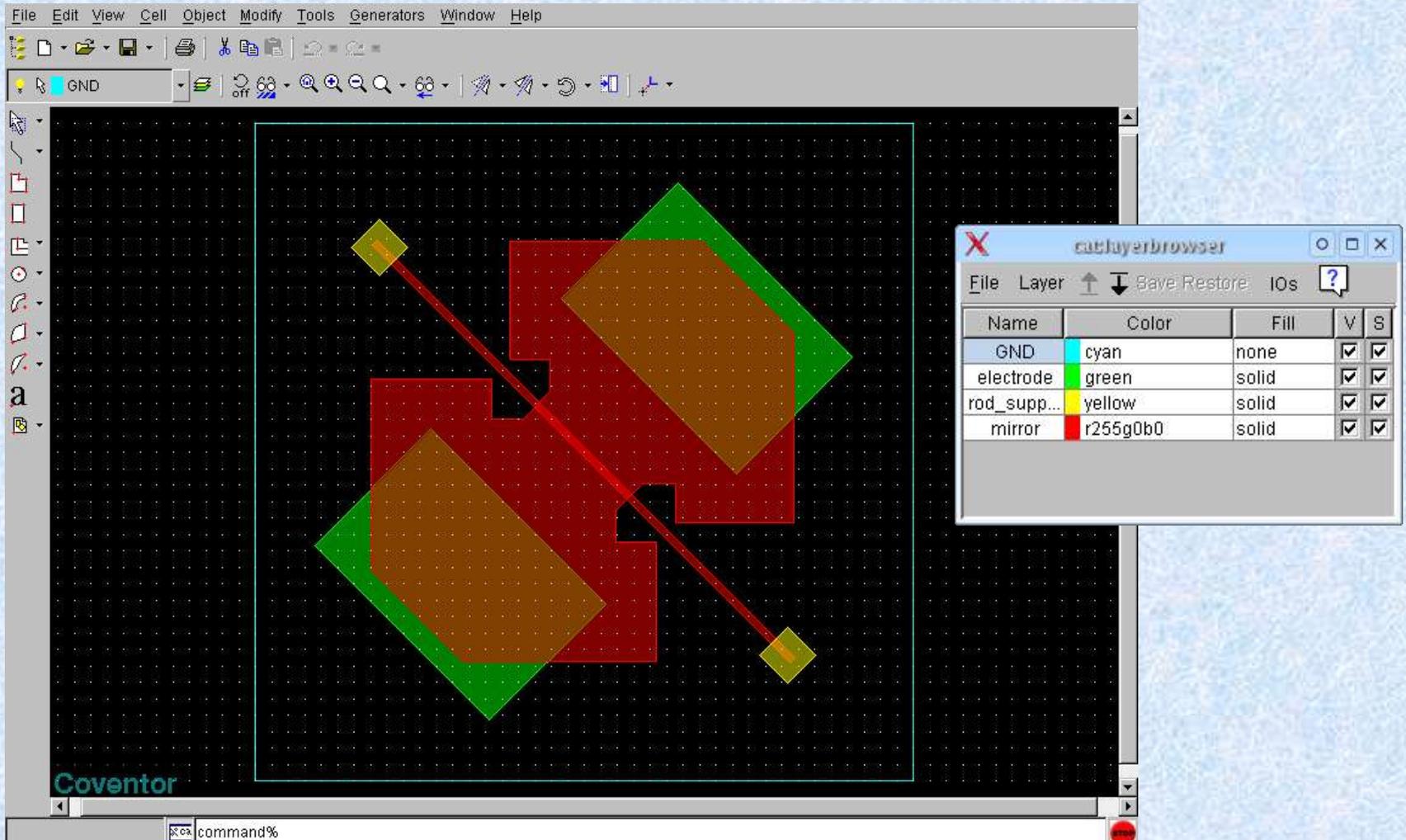
-
-
-
-
-
-
-
-
-

Proceso de fabricación

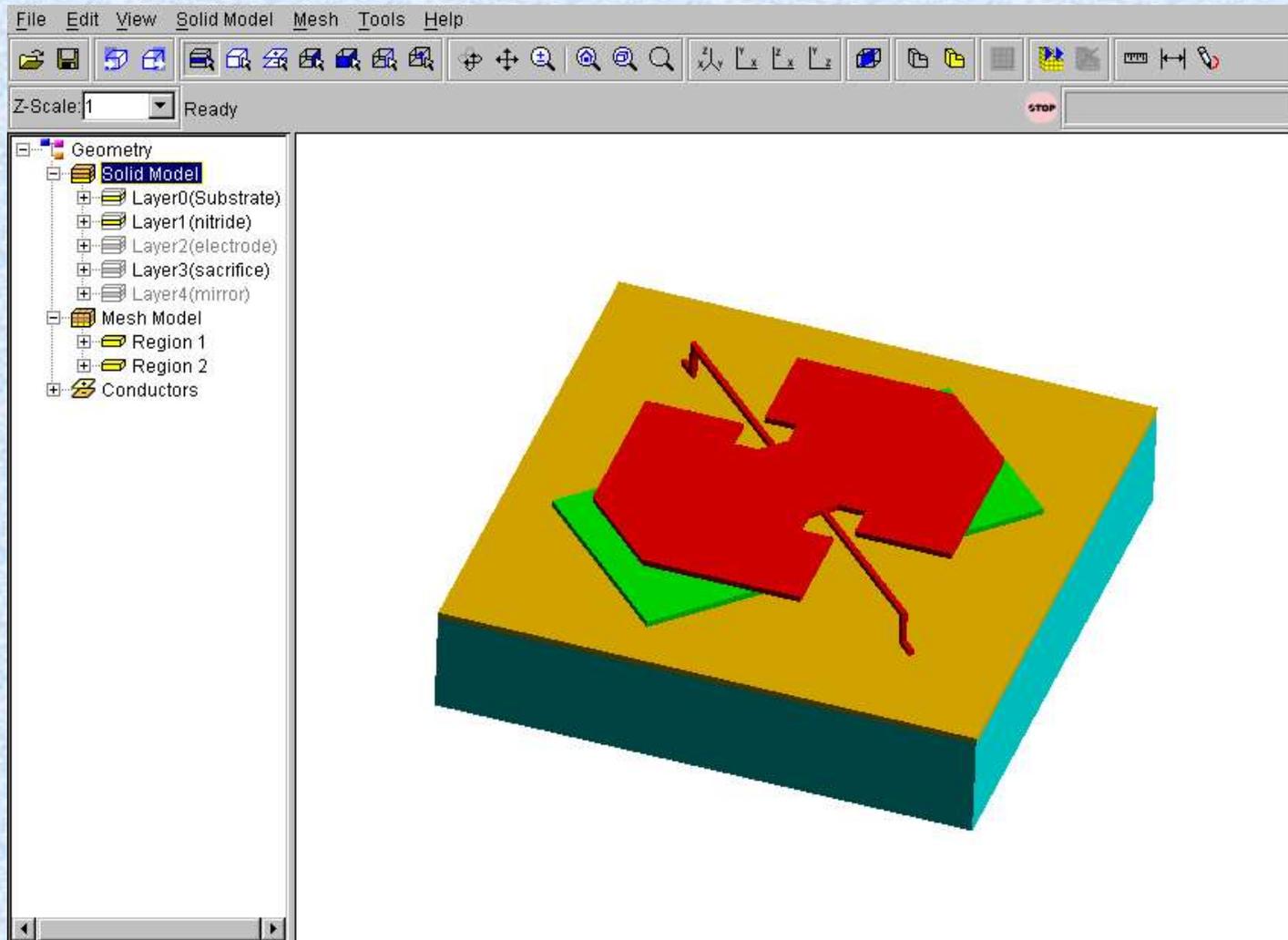


Step	Action	Type	Layer Name	Material	Thickne...	Color	Name/ Polarity	Depth	Offset	Sidewall Angle	Comment
0	Base		Substrate	SILICON	8.0	cyan	GND				
1	Depo...	Planar	nitride	SIN	0.5	orange					
2	Depo...	Planar	electrode	POLYSILICON	0.5	green					
3	Etch	Front, Last L...				green	electrode +	0.5	0.0	0.0	
4	Depo...	Planar	sacrifice	POLYIMIDE	2.0	yellow					
5	Etch	Front, Last L...				yellow	rod_supp... -	2.0	0.0	0.0	
6	Depo...	Conformal	mirror	ALUMINUM(FIL...	0.5	red					
7	Etch	Front, Last L...				red	mirror +	0.5	0.0	0.0	
8	Sacrif...			POLYIMIDE							

Editor de layout



Preprocesador



Propiedades y mallado

ID: 1
Name: electrode_2
Material: POLYSILICON

Analysis Options

Conductor Dielectric
 Solid Fluid
 Suppress, except for MemElectro

Geometry

Bounding Box (µm): X: -181.337997, -163.660
Y: -181.337997, -163.660
Z: 0.5, 1.0
Volume (µm³): 74.995038
Centroid (µm): (-172.499496, -172.499496)

Volume Mesh

Nodes: 231
Elements: 15
Element Type: PARABOLIC HEXAHEDRON

Surface Mesh

Nodes: 186
Elements: 46
Element Type: PARABOLIC QUADRILATERAL

OK Cancel ?

Mesh Type: Tetrahedrons
Element order: Linear Parabolic
Element size: 4.0
 Generate mesh
Advanced

OK Cancel ?

Mesh Type: Manhattan bricks
Element order: Linear Parabolic

X direction

Element size: 2.5
Bias type: None
Bias ratio: 1.0

Y direction

Element size: 2.5
Bias type: None
Bias ratio: 1.0

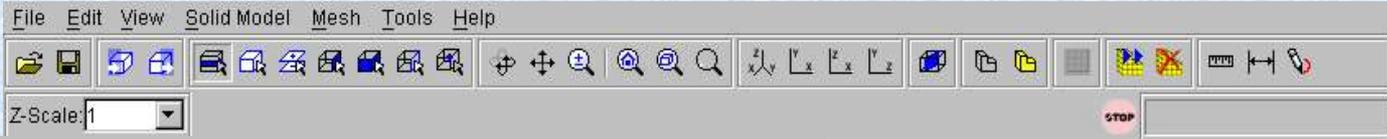
Z direction

Element size: 0.5
Bias type: None
Bias ratio: 1.0

Generate mesh
Advanced

OK Cancel ?

Mallado del modelo

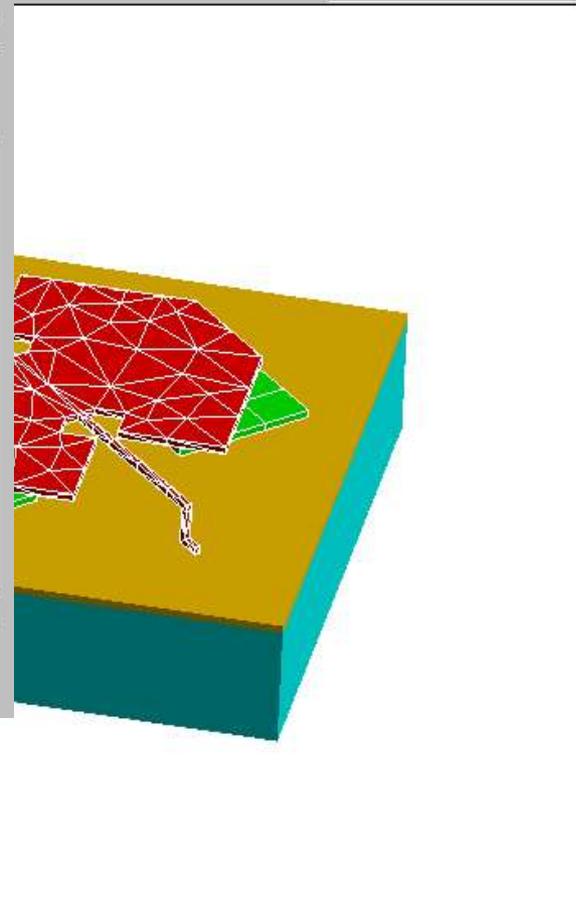


```
----- Summary: Mesh Element Aspect Ratio -----  
Number of volume elements           : 443  
Average volume element aspect ratio : 6.7674  
Minimum volume element aspect ratio : 1.27127  
Maximum volume element aspect ratio : 16.8837  
Summed volume element aspect ratio  : 2997.96  
  
Number of surface elements          : 496  
Average surface element aspect ratio : 2.55802  
Minimum surface element aspect ratio : 1  
Maximum surface element aspect ratio : 8.86794  
Summed surface element aspect ratio  : 1268.78
```

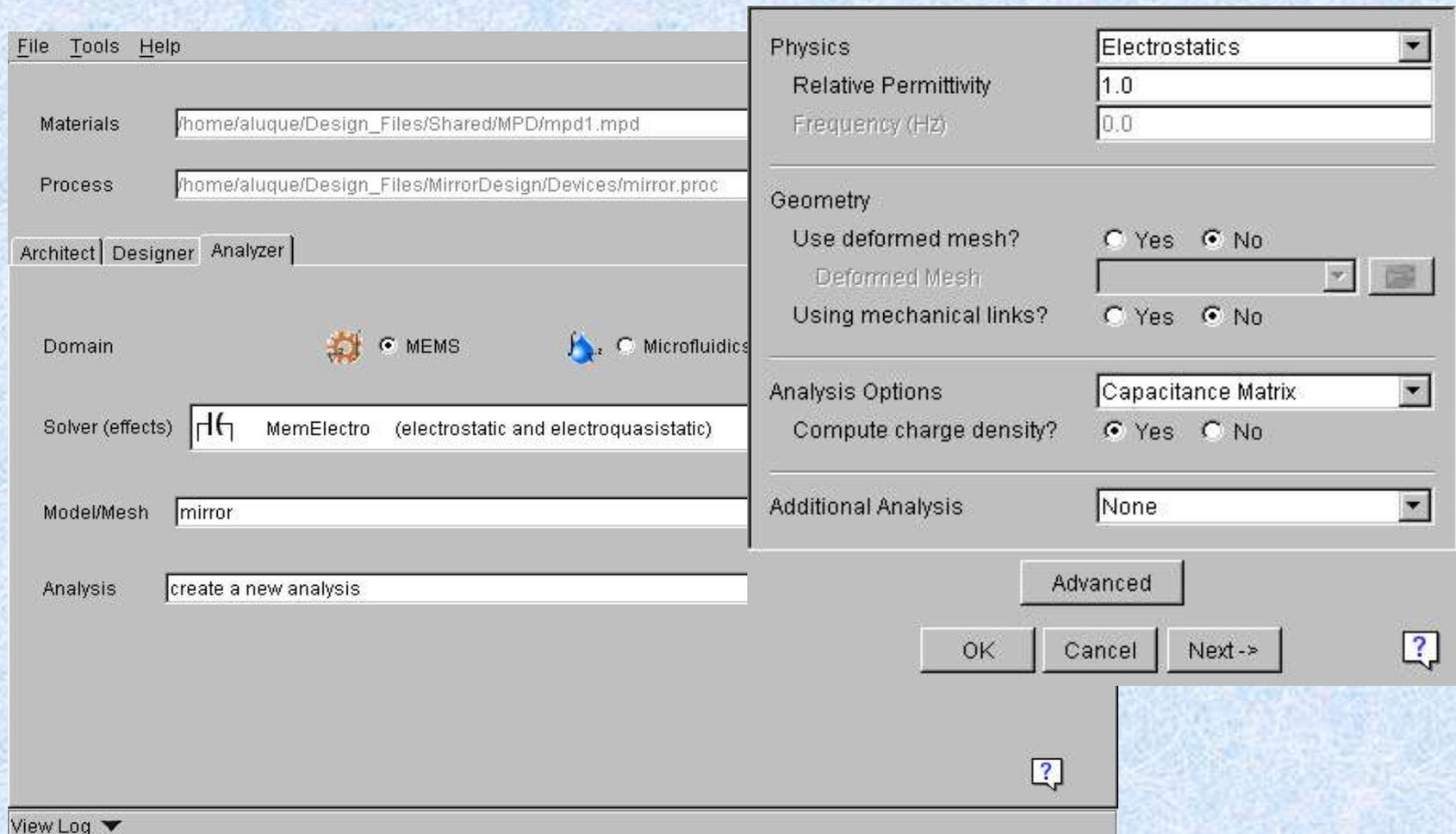
```
----- Histogram: Volume Mesh Element Aspect Ratio -----  
Aspect ratio range [1.27127,16.8837] / Number of values: 443
```

```
-----  
2,83250513 (6,99%) :*****  
4,39374455 (18,2%) :*****  
5,95498398 (20,0%) :*****  
7,51622341 (20,9%) :*****
```

OK ?



Simulación electromecánica



Condiciones eléctricas

Physics: Electrostatics

Relative Permittivity: 1.0

Frequency (Hz): 0.0

Geometry

Use deformed mesh? Yes No

Deformed Mesh: [] []

Using mechanical links? Yes No

Analysis Options: Capacitance Matrix

Compute charge density? Yes No

Additional Analysis: None

MemElect

ConductorBCs

DielectricBCs

SymmetryBCs

Parametric Study...

<- Back Close Run...

ConductorBCs	Conductor	BCType	Voltage	Charge	Variable
Setting	electrode1	Fixed	10.0	0.0	none
Setting	electrode2	Fixed	5.0	0.0	none
Setting	mirror	Fixed	0.0	0.0	none

OK Cancel ?

Condiciones mecánicas

Physics: Mechanical

Analysis Options

- Use prev. result: No
- Electrostatic Load: None
- Linear or Nonlinear?: Nonlinear
- Restart from prev. result: Yes No
- Time Dependence: SteadyState
- Stop Time(s): 1.0E-5
- Output Timestep(s): 1.0E-6
- Timestep Method: Fixed

SurfaceBCs

VolumeBCs

LinkageBCs

ContactBCs

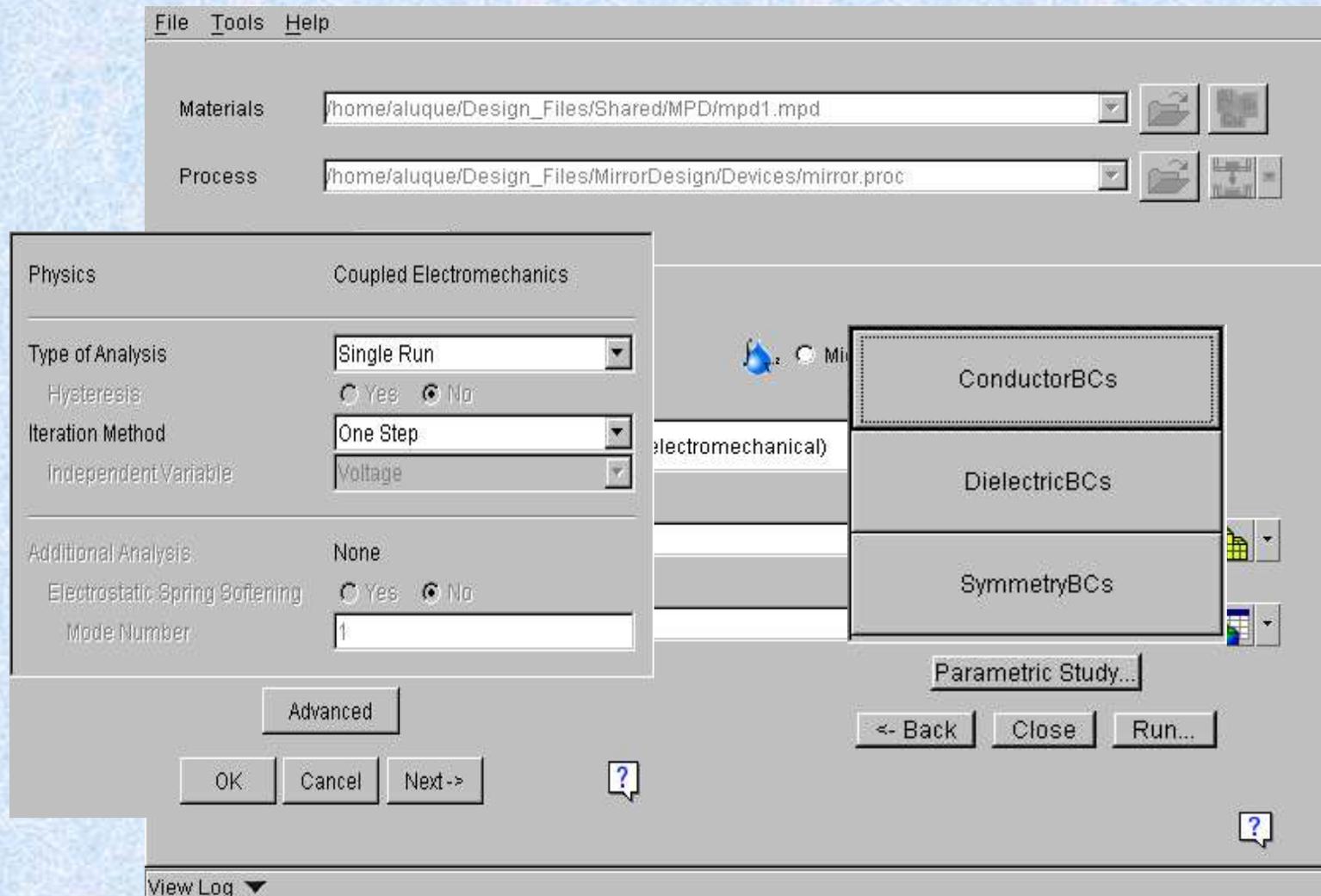
SurfaceBCs	FixType	Patch1	and1	Patch2	and2	Patch3	LoadValue	Variable	Transient
Set1	fixAll	end1	or	end2	and	none	Scalar 0.0	Fixed	Fixed
Set2	none	none	and	none	and	none	Scalar 0.0	Fixed	Fixed
Set3	none	none	and	none	and	none	Scalar 0.0	Fixed	Fixed
Set4	none	none	and	none	and	none	Scalar 0.0	Fixed	Fixed
Set5	none	none	and	none	and	none	Scalar 0.0	Fixed	Fixed
Set6	none	none	and	none	and	none	Scalar 0.0	Fixed	Fixed
Set7	none	none	and	none	and	none	Scalar 0.0	Fixed	Fixed
Set8	none	none	and	none	and	none	Scalar 0.0	Fixed	Fixed
Set9	none	none	and	none	and	none	Scalar 0.0	Fixed	Fixed
Set10	none	none	and	none	and	none	Scalar 0.0	Fixed	Fixed
Set11	none	none	and	none	and	none	Scalar 0.0	Fixed	Fixed
Set12	none	none	and	none	and	none	Scalar 0.0	Fixed	Fixed

OK Cancel

Advanced

OK Cancel Next ->

Condiciones acopladas



Resultados (I)

Solver: CoSolveEM
 Model/Mesh: cs_1_mirror_prebuilt.mbif

Results Summary

Tables: **Capacitance (pF)**

Graphs: Displacements

Custom Query ...

3D Results

Load Result: cs_1_mirror_prebuilt

Close

Capacitance (pF)	electrode1	electrode2	mirror
electrode1	1.163735E-03	-7.376879E-05	-1.089966E-03
electrode2	-7.376879E-05	1.135657E-03	-1.061888E-03
mirror	-1.089966E-03	-1.061888E-03	2.151854E-03

Close

electroBCs	Voltage (V)	Charge (pC)
electrode1	1.000000E01	1.126850E-02
electrode2	5.000000E00	4.940604E-03
mirror	0.0	-1.620910E-02

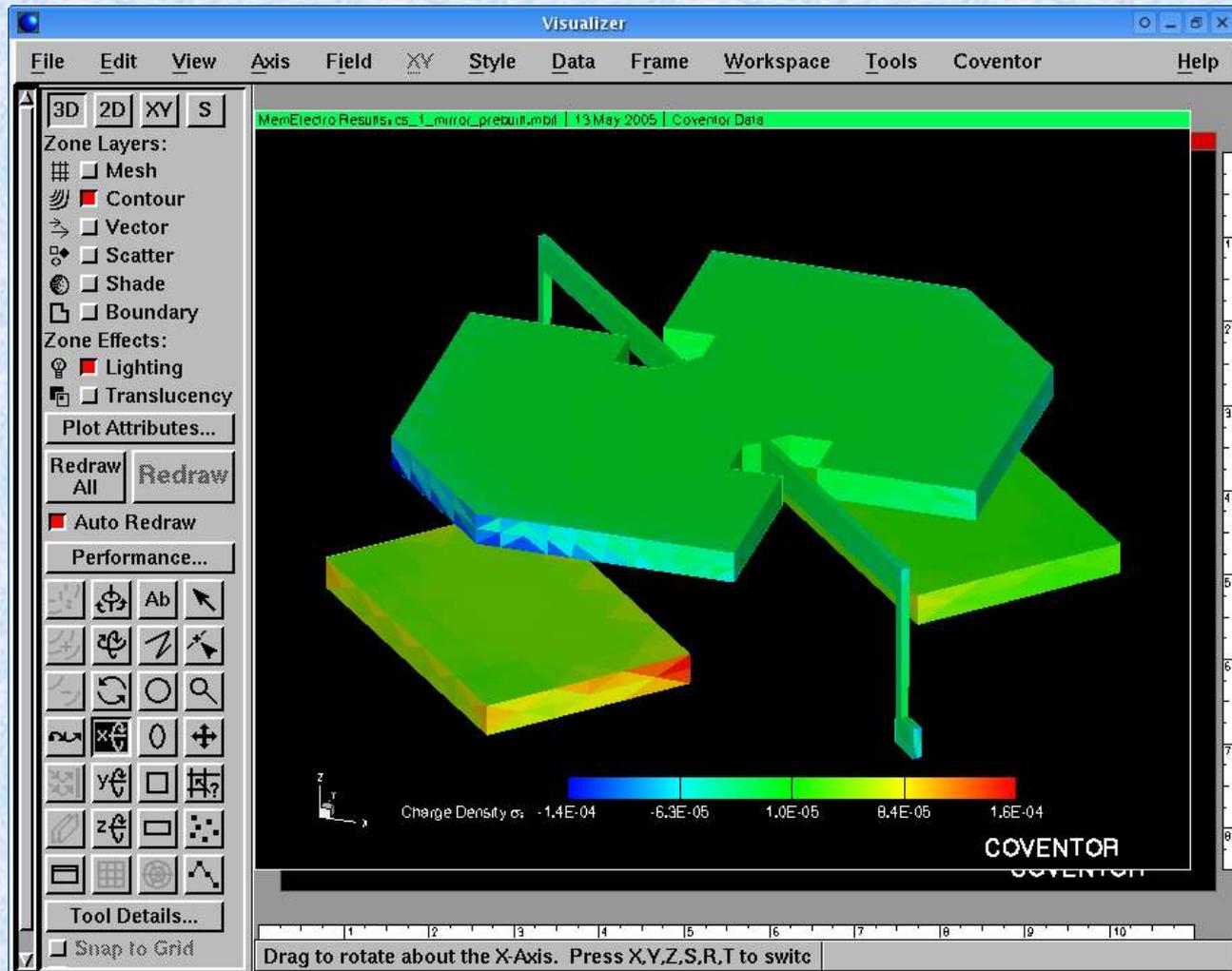
Close

mechDomain	Maximum	Minimum
Node Displacement	7.025104E-02	0.0
Node X Displacement	5.531611E-04	-3.368897E-03
Node Y Displacement	6.641096E-04	-3.304879E-03
Node Z Displacement	4.595700E-02	-7.024788E-02

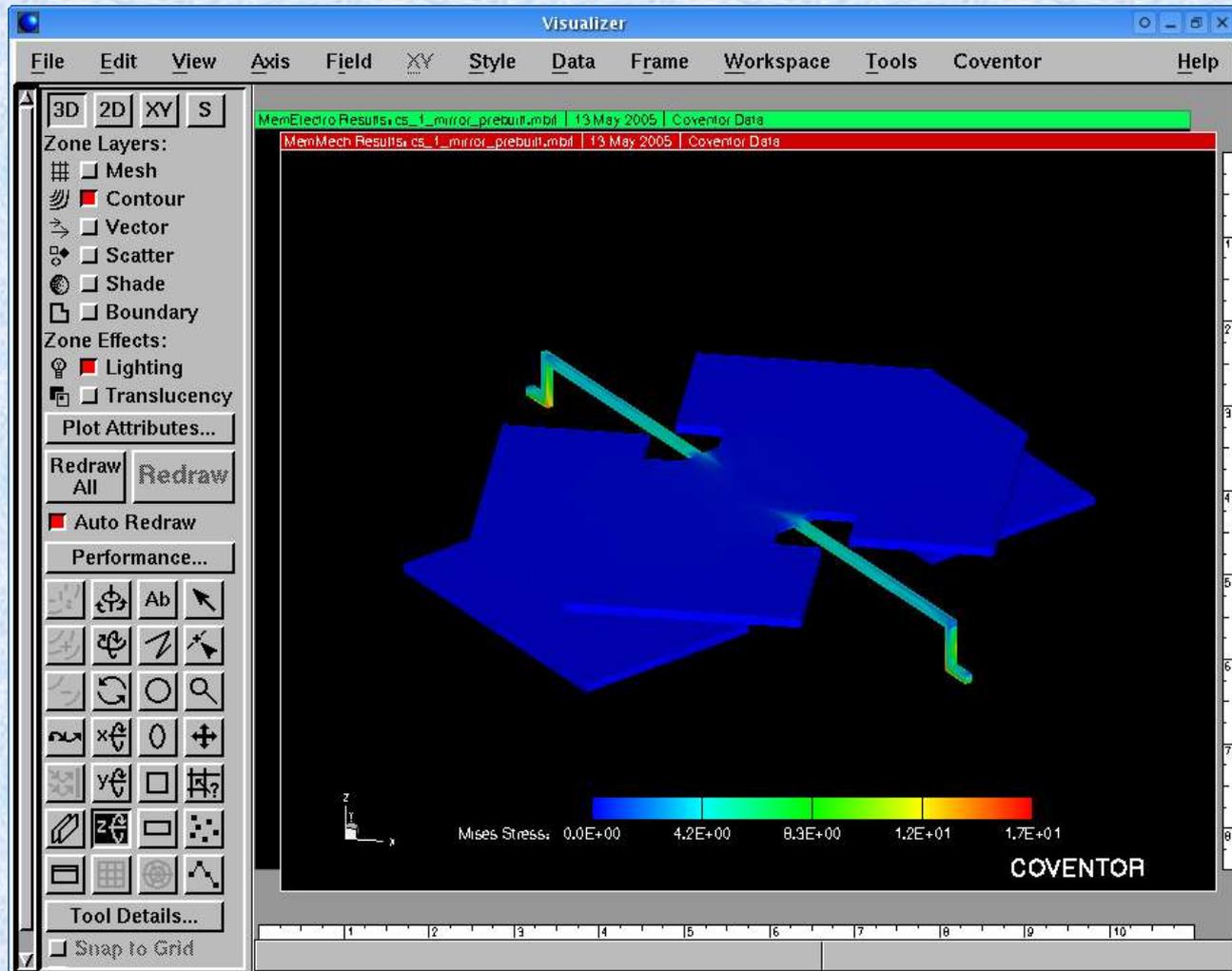
rxnForces	Fx	Fy	Fz
end1	-7.412191E-02	7.568033E-02	1.000949E-02
end2	7.562150E-02	-7.415342E-02	9.795593E-03

Close

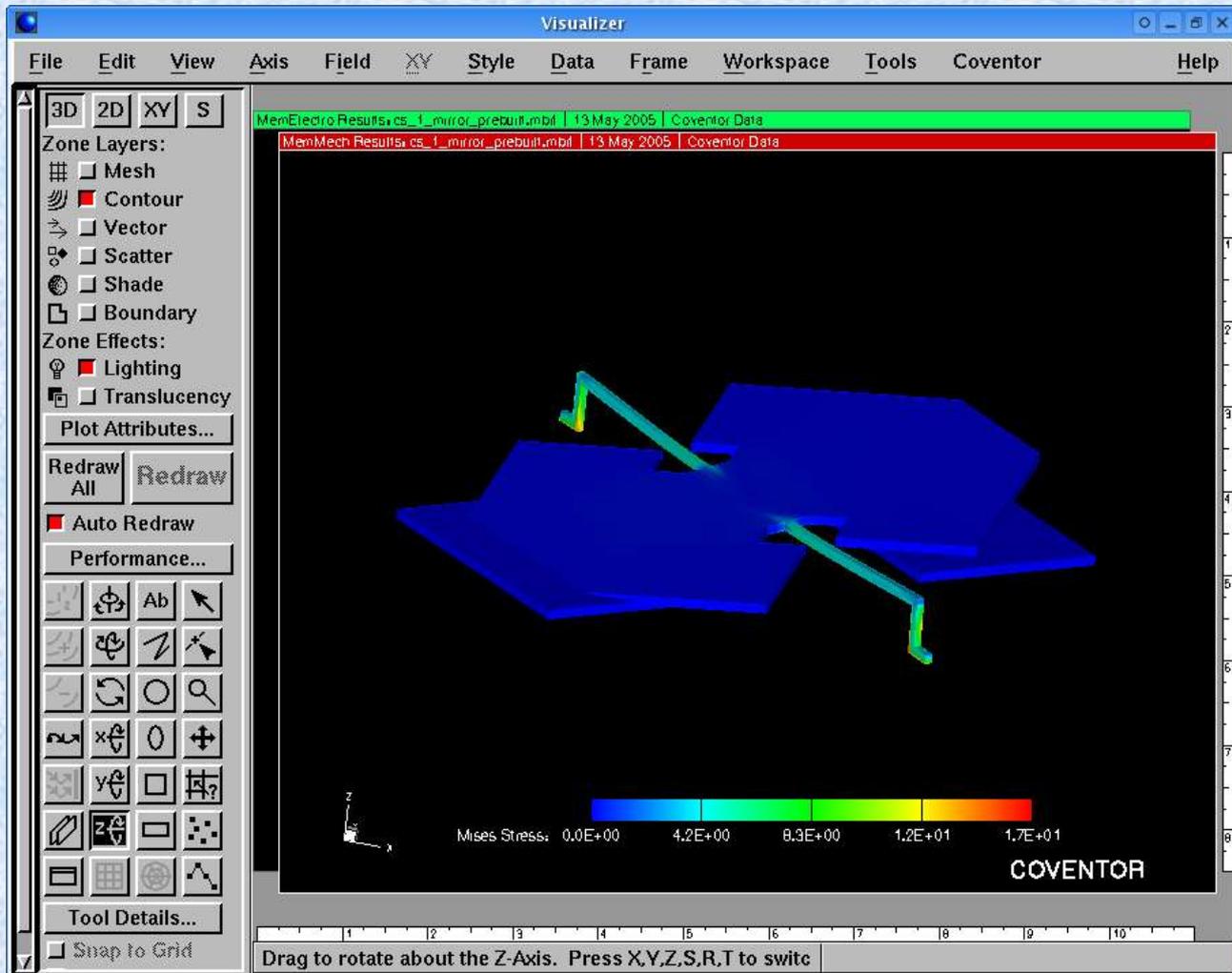
Resultados (II)



Resultados (III)



Resultados (y IV)



•
•
•

Índice

- Diseño y simulación
- Software profesional
- Características
- CoventorWare
- ACES

ACES

- Anisotropic Crystalline Etching Simulator
- Simulador de grabado del silicio. Trata las diferentes orientaciones cristalográficas y propiedades del atacante
- Método de simulación basado en átomos. Cálculo dinámico para reducir el consumo de memoria.

•
•
•

ACES

- Interfaz de usuario amigable
- Cualquier forma de máscara
- Tasas de grabado modificables
- Visor tridimensional
- Resultados verificados experimentalmente
- ¡GRATIS!

ACES

