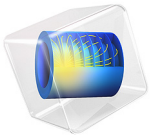


Model created in COMSOL Multiphysics 6.4

Normal Modes of a Biased Resonator — 3D Geometry from a GDS-File

Introduction

When modeling a MEMS or semiconductor device with complex 3D structure, the geometry buildup can be time consuming, tedious, and error-prone. Buildup can require numerous primitive shapes in an assembly that does not correspond to how such a device would be fabricated, that is, through sequence of processes that deposit and pattern the distinct materials one layer at a time. This tutorial demonstrates how, with the ECAD Import, and Design Modules, we can emulate semiconductor fabrication processes to build 3D geometry more efficiently and in a way that reflects actual semiconductor or MEMS fabrication.

This tutorial recreates from a GDS file the device structure modeled in the Stationary Analysis of a Biased Resonator — 3D using operations available in the ECAD Import, and Design Modules. The original model was created from 15 rectangles specified by 60 parameters. In contrast, this tutorial builds the geometry layer-by-layer and requires only 6 parameters for specifying thicknesses of the layers which greatly simplifies future optimization studies.

After the geometry model is completed, the tutorial solves for the eigenmodes of the structure which can be compared to the results in the Normal Modes of a Biased Resonator — 3D.

Model Definition

The following is an outline of the steps that you can use to emulate basic MEMS or semiconductor fabrication processes using geometry operations. For the detailed instructions see the Modeling Instructions section.

DEPOSITION OF A LAYER OF MATERIAL OVER A FLAT SURFACE

To create the geometry for a layer deposited over a flat surface, use an **Import** operation. Depending on the mask in GDS file, the resulting layer could be patterned or unpatterned.

During the import the layer is extruded according to the specified thickness and elevation values. The substrate layer imported in this way is shown in Figure 1.

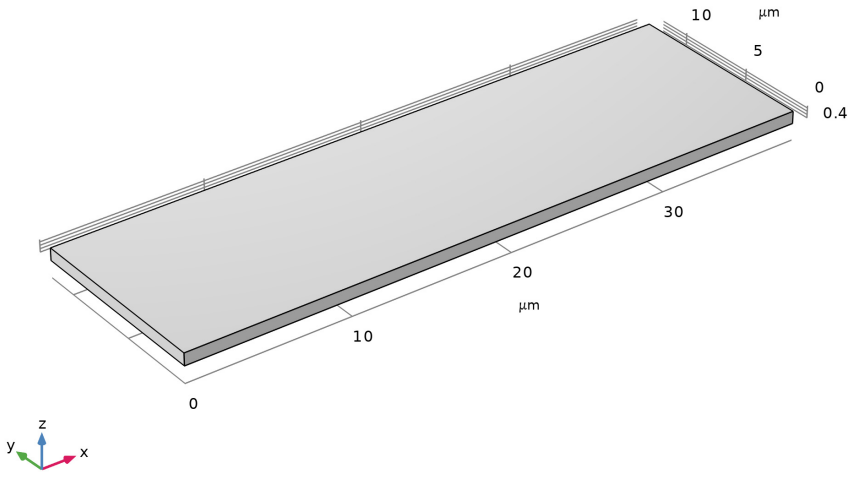


Figure 1: First imported layer: substrate.

The unpatterned nitride layer, imported as the second layer in the structure is shown Figure 2.

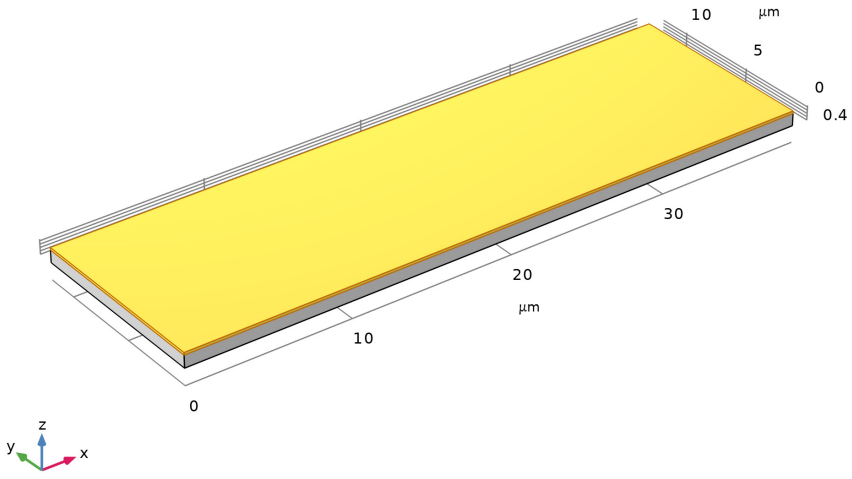


Figure 2: Second imported layer: nitride.

DEPOSITION AND PATTERNING OF A LAYER OF MATERIAL OVER A FLAT SURFACE

When a patterned layer is deposited over a flat surface, and the GDS file contains the mask for the layer when using positive photoresist, the imported layer can be directly extruded by the Import operation. The import then replicates the sequence of processes that include material deposition, photoresist coating and exposure, etching of the material, and the photoresist stripping. In the model, this is illustrated by importing layer 3 and layer 4 that

correspond to polysilicon base layer and bottom electrode layer, respectively, as shown in Figure 3 and Figure 4

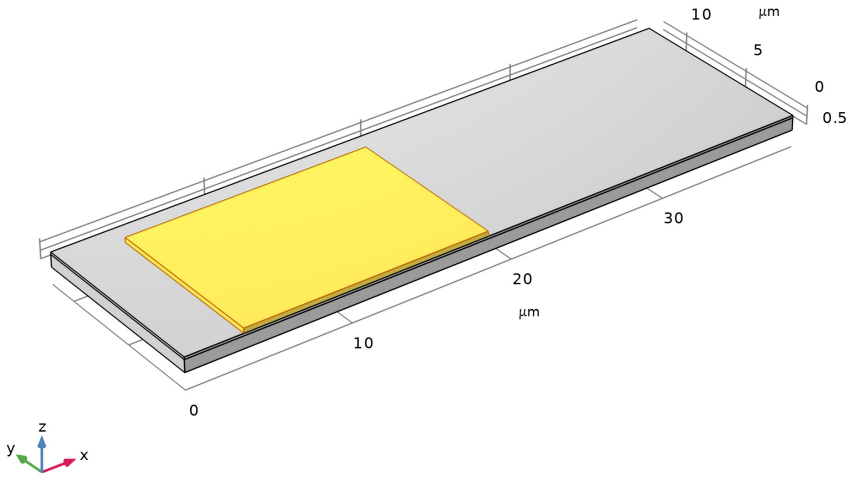


Figure 3: Third imported layer: patterned polysilicon base.

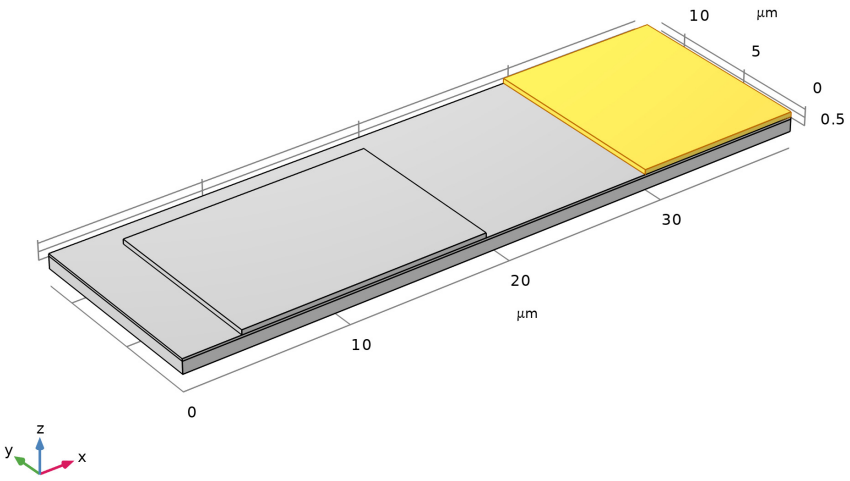


Figure 4: Fourth imported layer: patterned bottom electrode.

CONFORMAL DEPOSITION OF A LAYER OF MATERIAL OVER NONFLAT SURFACE

Two layers in this structure are deposited over a nonflat surface: the sacrificial layer and the polysilicon layer for the beam. You can follow the same procedure for creating both layers. The following is an overview for how to create the sacrificial layer which covers the patterned polysilicon base, bottom electrode, and the exposed areas of the nitride layer. This layer is thus to be created over a nonflat surface, so the import operation cannot be used to extrude the layer mask. Instead, a sequence of geometry operations that includes **Union Selection**, **Union**, **Box Selection**, and **Offset Faces** should be used to emulate the deposition of the material.

First, use **Union Selection** to select previously imported layers (geometry objects) for use in the following **Union** operation. Second, use **Union** to unite previously imported layers (geometry objects) so its faces (outer surfaces) could be selected in the following **Box Selection** operation. Next, use **Box Selection** to select the boundaries of the geometry to be used in the following **Offset operation** as the faces to offset. Finally, use **Offset Faces** to

'grow' the layer over the selected boundaries. The result of these operations is shown in Figure 5.

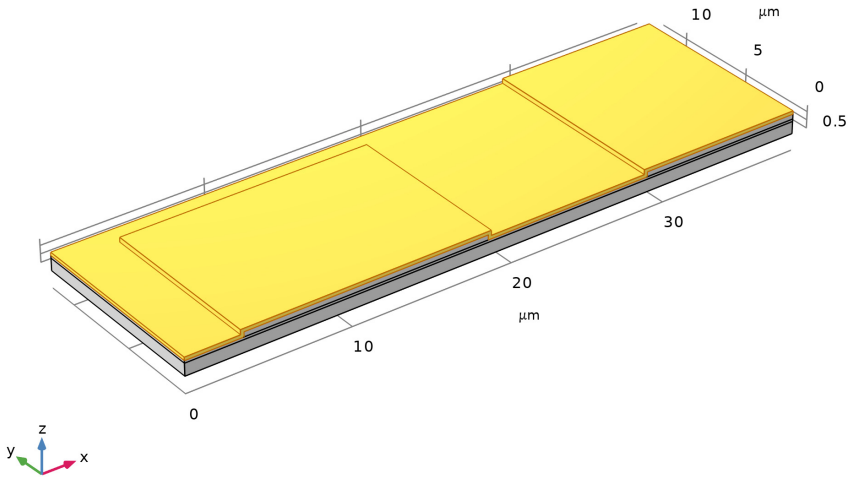


Figure 5: Sacrificial layer. This layer is conformal to the underlying polysilicon base and bottom electrode.

COATING AND PATTERNING OF VIRTUAL PHOTORESIST

The patterning of the conformal sacrificial layer can be done in two steps. First, create a virtual photoresist by importing the mask layer. This is equivalent to photoresist coating and lithographic patterning, as shown in Figure 6. In the subsequent step, use the Intersection operation to transfer the pattern of the virtual photoresist to the target layer. The virtual photoresist layer must penetrate the entire depth of the target layer, so this determines the elevation and thickness of the imported mask layer.

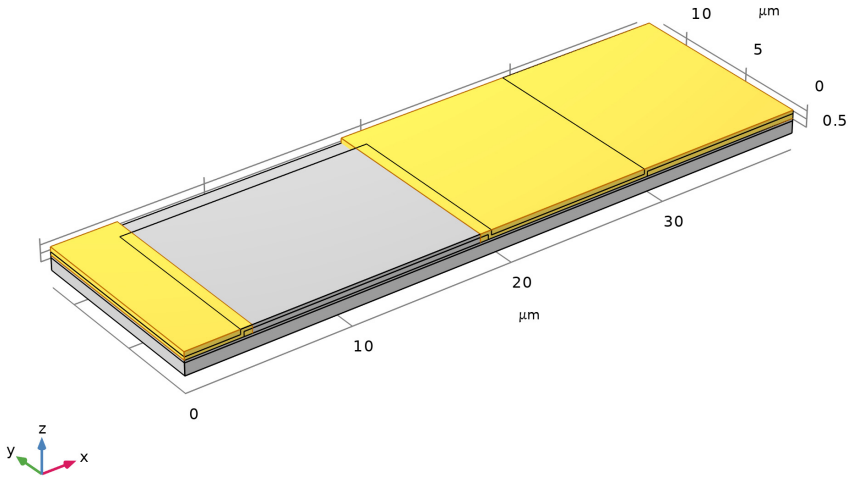


Figure 6: Patterned virtual photoresist layer.

PATTERNING OF A LAYER OF MATERIAL OVER NONFLAT SURFACE

By using the Intersection operation, you can transfer the photoresist pattern to the target sacrificial layer. This step is equivalent to an etch process followed by a photoresist strip. What remains is the patterned sacrificial layer, as seen in Figure 7.

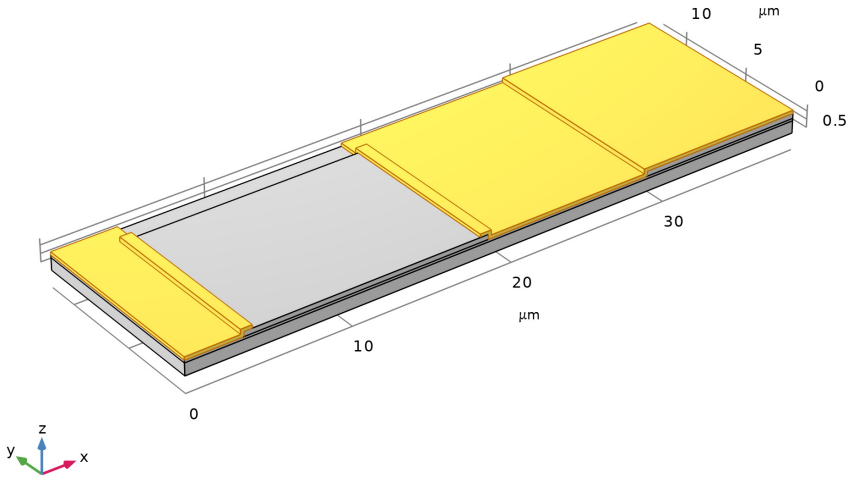


Figure 7: Patterned sacrificial layer.

To obtain the patterned polysilicon beam deposited over the sacrificial layer and the exposed faces of the polysilicon base and nitride layers, follow the same steps for creating the sacrificial layer. The result is shown in Figure 8.

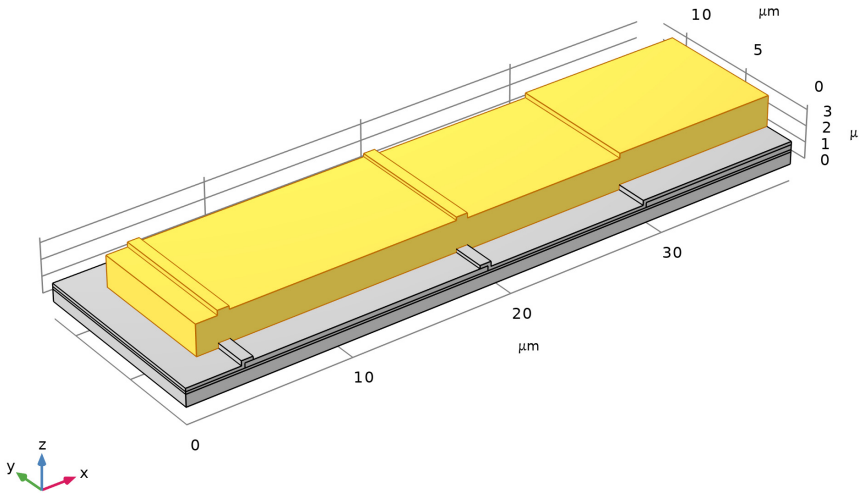


Figure 8: Patterned polysilicon beam.

REMOVAL OF A LAYER OF MATERIAL

To remove the sacrificial layer seen in Figure 9 use the Delete Entities operation. This step is equivalent to an isotropic etch process for releasing the structure. The completed half structure is shown in Figure 10.

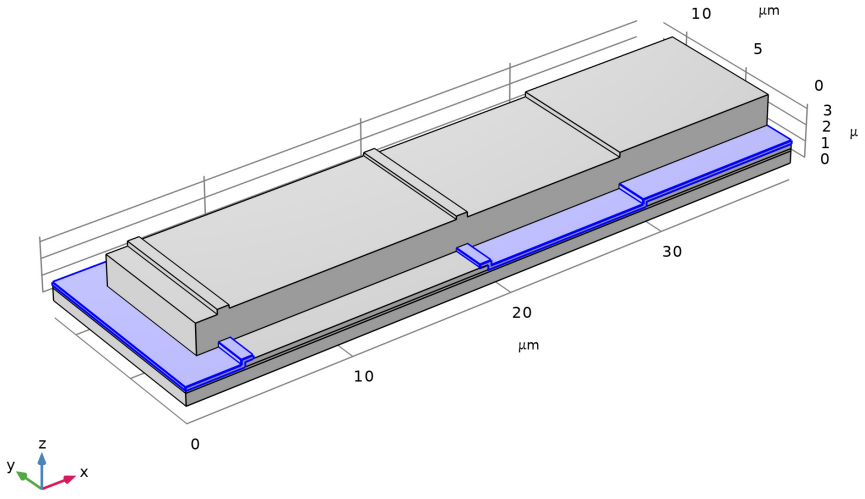


Figure 9: The patterned sacrificial layer under the polysilicon beam is selected for removal.

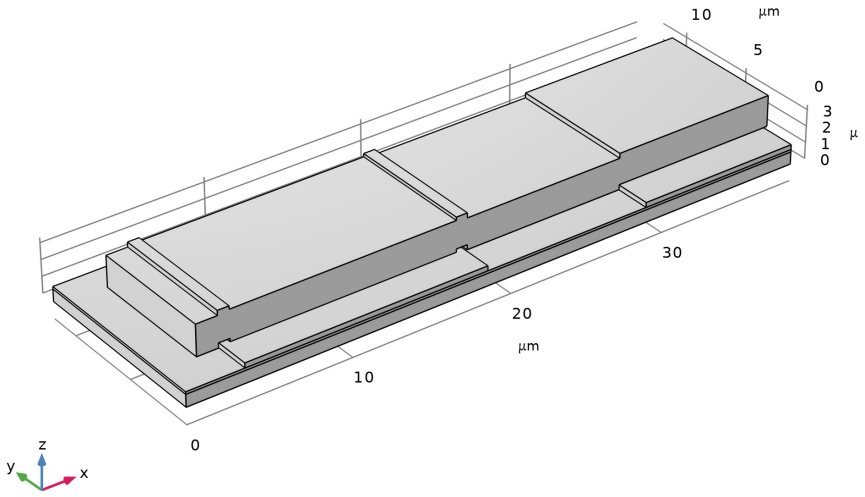


Figure 10: Completed half of the geometry.

For this tutorial it is not enough to model half of the geometry using symmetry boundary conditions, because doing so excludes all the antisymmetric vibrational modes. The geometry is therefore mirrored prior to performing the eigenfrequency analysis.

Results and Discussion

Figure 11, Figure 12, and Figure 13 show the normal modes of the device, together with the eigenfrequencies, in the unbiased state. The lowest three normal modes are symmetric and anti-symmetric bending modes and a torsional mode. These results are similar to those in Normal Modes of a Biased Resonator — 3D.

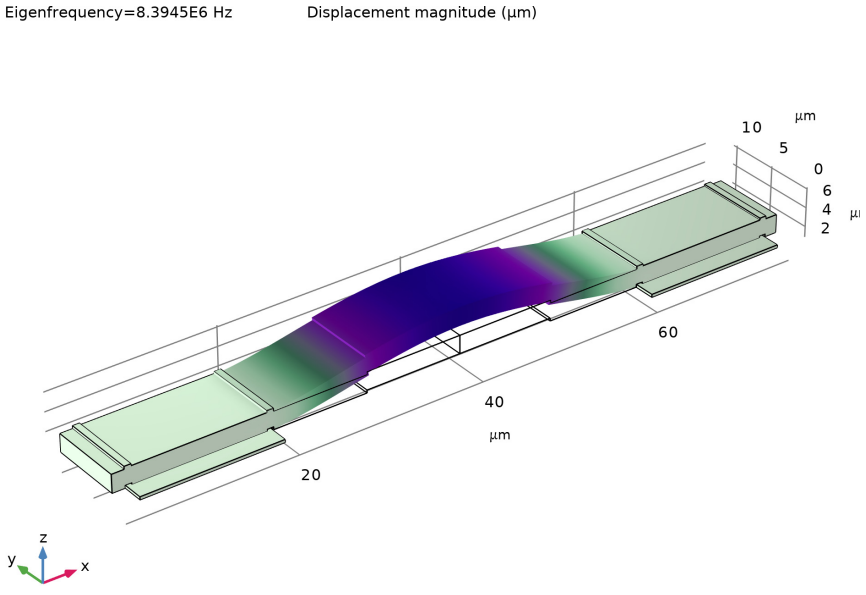


Figure 11: Symmetric bending mode, f_0 = 8.4 MHz.

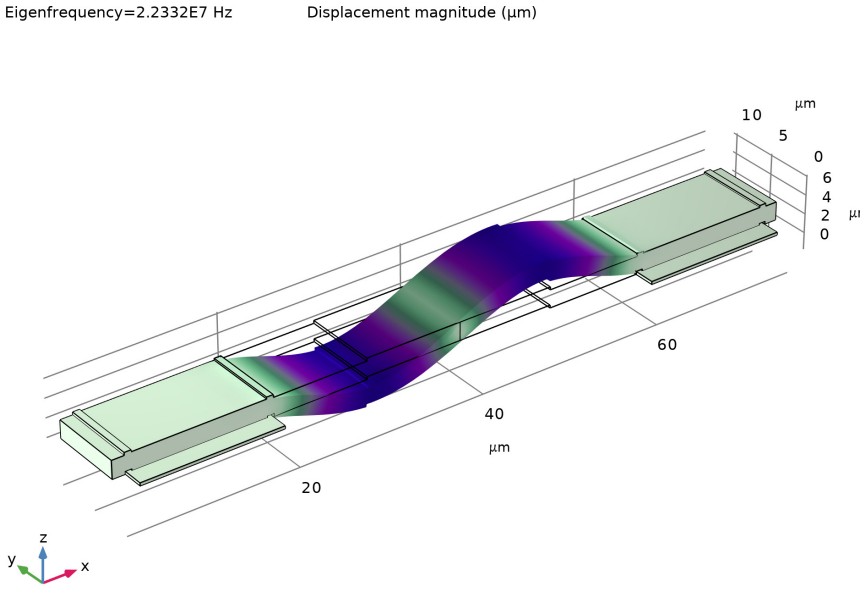


Figure 12: Antisymmetric bending mode, f_0 = 22.3 MHz.

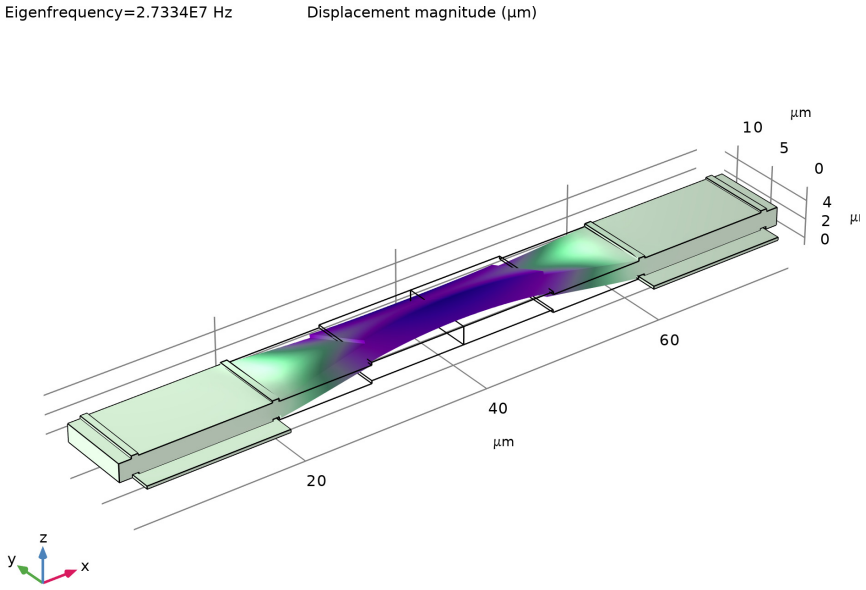


Figure 13: Torsional mode, f_0 = 27.2 MHz.

Application Library path: `MEMS_Module/Actuators/biased_resonator_3d_ecad_design`

Modeling Instructions

Create a 3D model with a **Solid Mechanics** interface.

From the **File** menu, choose **New**.

NEW

In the **New** window, click **Model Wizard**.

MODEL WIZARD

1 In the **Model Wizard** window, click **3D**.

2 In the **Select Physics** tree, select **Structural Mechanics** > **Solid Mechanics (solid)**.

3 Click **Add**.

4 Click **Study**.

5 In the **Select Study** tree, select **General Studies** > **Eigenfrequency**.

6 Click **Done**.

GLOBAL DEFINITIONS

Enter the parameters used for creating the geometry.

Parameters 1

1 In the **Model Builder** window, under **Global Definitions** click **Parameters 1**.

2 In the **Settings** window for **Parameters**, locate the **Parameters** section.

3 In the table, enter the following settings:

Name	Expression	Value	Description
t_sub	0.75[um]	7.5E-7 m	Thickness of substrate
t_nitride	0.15[um]	1.5E-7 m	Thickness of nitride layer
t_base	0.3[um]	3E-7 m	Thickness of polysilicon base layer
t_sl	0.2[um]	2E-7 m	Thickness of sacrificial layer
t_poly	1.9[um]	1.9E-6 m	Thickness of polysilicon layer
w_box	38.9[um]	3.89E-5 m	Width of box

GEOMETRY 1

While it is possible to import all layers at the same time, it is easier to view the resulting 3D geometry if you import and build the layers one at a time.

1 In the **Model Builder** window, expand the **Component 1 (comp1)** > **Geometry 1** node, then click **Geometry 1**.

2 In the **Settings** window for **Geometry**, locate the **Units** section.

3 From the **Length unit** list, choose **µm**.

In addition to the ECAD Import Module functionality, the **Offset Faces** operation, which is available in the Design Module, is used to create the geometry. Make sure that the CAD kernel is used.

4 Locate the **Advanced** section. From the **Geometry representation** list, choose **CAD kernel**.

Import 1 = L1, Substrate

Start with importing the substrate.

1 In the **Geometry** toolbar, click **Import**.

2 In the **Settings** window for **Import**, type `Import 1 = L1, Substrate` in the **Label** text field.

3 Locate the **Source** section. Click **Browse**.

4 Browse to the model's Application Libraries folder and double-click the file `biased_resonator_3d_ecad_design_layout.gds`.

5 Locate the **Layers** section. Select the **Manual control of elevations** checkbox.

6 In the table, enter the following settings:

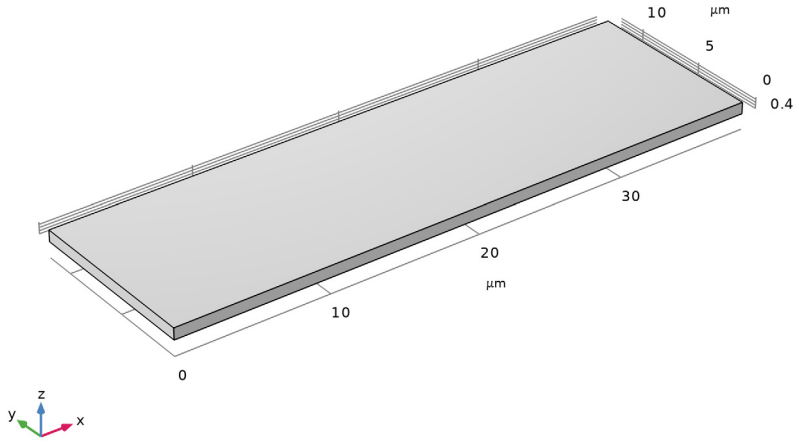
Name	Type	Thickness (µm)	Elevation (µm)	Import
LAYER10	Metal	t_sub	0	√
LAYER20	Metal	0	0	
LAYER31	Metal	0	0	
LAYER32	Metal	0	0	
LAYER40	Metal	0	0	
LAYER50	Metal	0	0	

7 Click to expand the **Selections of Resulting Entities** section. Find the **Cumulative selection** subsection. Click **New**.

8 In the **New Cumulative Selection** dialog, type `Substrate` in the **Name** text field.

9 Click **OK**.

10 In the **Settings** window for **Import**, click **Build Selected**.



Import 2 = L2, Deposit Nitride Layer

Continue with creating the nitride layer. The easiest is to duplicate the previous import, then edit the settings for importing Layer 2 from the file.

1 Right-click **Import 1 = L1, Substrate** and choose **Duplicate**.

2 In the **Settings** window for **Import**, type `Import 2 = L2, Deposit Nitride Layer` in the **Label** text field.

3 Locate the **Layers** section. In the table, enter the following settings:

Name	Type	Thickness (μm)	Elevation (μm)	Import
LAYER10	Metal	t_sub	0	
LAYER20	Metal	t_nitride	t_sub	√

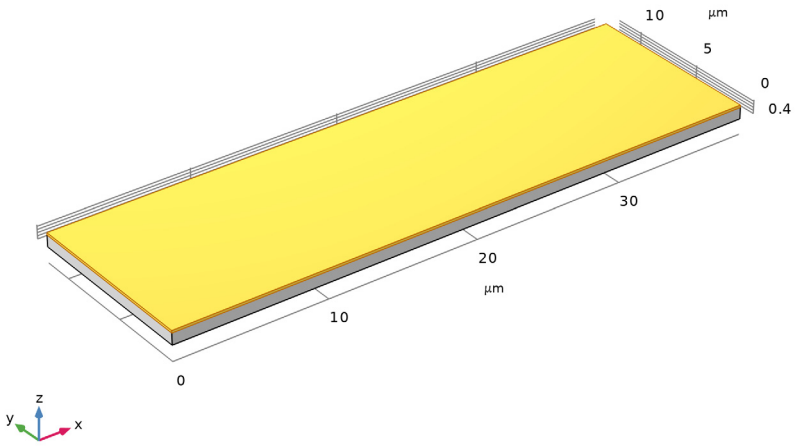
4 Click to expand the **Selections of Resulting Entities** section. Find the **Cumulative selection** subsection. Click **New**.

5 In the **New Cumulative Selection** dialog, type `Nitride` in the **Name** text field.

6 Click **OK**.

7 In the **Settings** window for **Import**, click **Build Selected**.

8 Click **Highlight Result**, for a better visualization of the result from the import.



Import 3 = L3, Deposit and Pattern Base Layer

Next, create the polysilicon base layer. The mask for this is Layer 3 in the GDS file. This is a patterned layer, but as it is deposited over a flat surface, you can import and extrude it in one step, just as the previous two layers.

1 Right-click **Import 2 = L2, Deposit Nitride Layer** and choose **Duplicate**.

2 In the **Settings** window for **Import**, type `Import 3 = L3, Deposit and Pattern Base Layer` in the **Label** text field.

3 Locate the **Layers** section. In the table, enter the following settings:

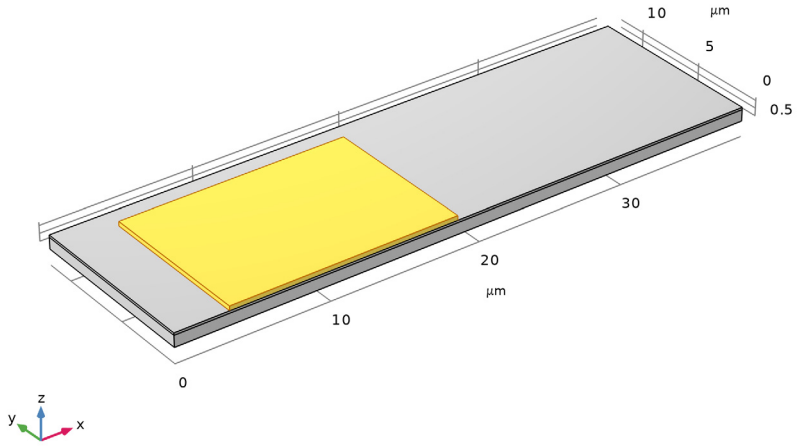
Name	Type	Thickness (μm)	Elevation (μm)	Import
LAYER20	Metal	`t_nitride`	`t_sub`	
LAYER31	Metal	`t_base`	`t_sub+t_nitride`	√

4 Click to expand the **Selections of Resulting Entities** section. Find the **Cumulative selection** subsection. Click **New**.

5 In the **New Cumulative Selection** dialog, type `Polysilicon Beam` in the **Name** text field.

6 Click **OK**.

7 In the **Settings** window for **Import**, click **Build Selected**.



Import 4 = L4, Deposit and Pattern Bottom Electrode Layer

1 Right-click **Import 3 = L3, Deposit and Pattern Base Layer** and choose **Duplicate**.

Next, create the bottom electrode layer. The mask for this is Layer 4 in the GDS file. This is a patterned layer, but as it is deposited over a flat surface, you can import and extrude it in one step, just as the previous layers.

2 In the **Settings** window for **Import**, type `Import 4 = L4, Deposit and Pattern Bottom Electrode Layer` in the **Label** text field.

3 Locate the **Layers** section. In the table, enter the following settings:

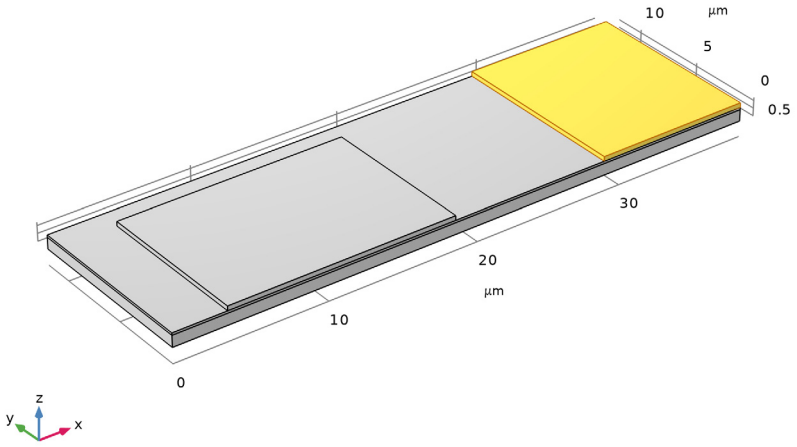
Name	Type	Thickness (μm)	Elevation (μm)	Import
LAYER31	Metal	`t_base`	`t_sub+t_nitride`	
LAYER32	Metal	`t_base`	`t_sub+t_nitride`	√

4 Click to expand the **Selections of Resulting Entities** section. Find the **Cumulative selection** subsection. Click **New**.

5 In the **New Cumulative Selection** dialog, type `Bottom Electrode` in the **Name** text field.

6 Click **OK**.

7 In the **Settings** window for **Import**, click **Build Selected**.



Union Selection 1 (unisel1)

Continue with creating the sacrificial layer, which is deposited over the polysilicon base, as well as the exposed nitride layer. Before importing the mask for the sacrificial layer, emulate its deposition by using the **Offset Faces** operation to offset in the normal direction the top faces of the nitride and polysilicon layers, and the exposed vertical faces of the polysilicon islands.

1 In the **Geometry** toolbar, click **Selections** and choose **Union Selection**.

2 In the **Settings** window for **Union Selection**, locate the **Geometric Entity Level** section.

3 From the **Level** list, choose **Object**.

4 Locate the **Input Entities** section. Click **Add**.

5 In the **Add** dialog, in the **Selections to add** list, choose **LAYER20 (Import 2 = L2, Deposit Nitride Layer)**, **LAYER31 (Import 3 = L3, Deposit and Pattern Base Layer)**, and **LAYER32 (Import 4 = L4, Deposit and Pattern Bottom Electrode Layer)**.

6 Click **OK**.

Union 1 (uni1)

1 In the **Geometry** toolbar, click **Booleans and Partitions** and choose **Union**.

2 In the **Settings** window for **Union**, locate the **Union** section.

3 From the **Input objects** list, choose **Union Selection 1**.

4 Select the **Keep input objects** checkbox.

5 Clear the **Keep interior boundaries** checkbox.

6 Locate the **Selections of Resulting Entities** section. Select the **Resulting objects selection** checkbox.

Box Selection 1 (boxsel1)

1 In the **Geometry** toolbar, click **Selections** and choose **Box Selection**.

2 In the **Settings** window for **Box Selection**, locate the **Geometric Entity Level** section.

3 From the **Level** list, choose **Boundary**.

4 Locate the **Input Entities** section. From the **Entities** list, choose **From selections**.

5 Click **Add**.

6 In the **Add** dialog, select **Union 1** in the **Selections** list.

7 Click **OK**.

8 In the **Settings** window for **Box Selection**, locate the **Box Limits** section.

9 In the **x minimum** text field, type `1`.

10 In the **x maximum** text field, type `35`.

11 In the **y minimum** text field, type `1`.

12 In the **y maximum** text field, type `11`.

13 In the **z minimum** text field, type `t_sub+t_nitride-0.01`.

Offset Faces 1 - Deposit Sacrificial Layer

1 In the **Geometry** toolbar, click **Editing** and choose **Offset Faces**.

2 In the **Settings** window for **Offset Faces**, type `Offset Faces 1 - Deposit Sacrificial Layer` in the **Label** text field.

3 Locate the **Faces** section. From the **Faces to offset** list, choose **Box Selection 1**.

4 Select the **Subtract input objects** checkbox.

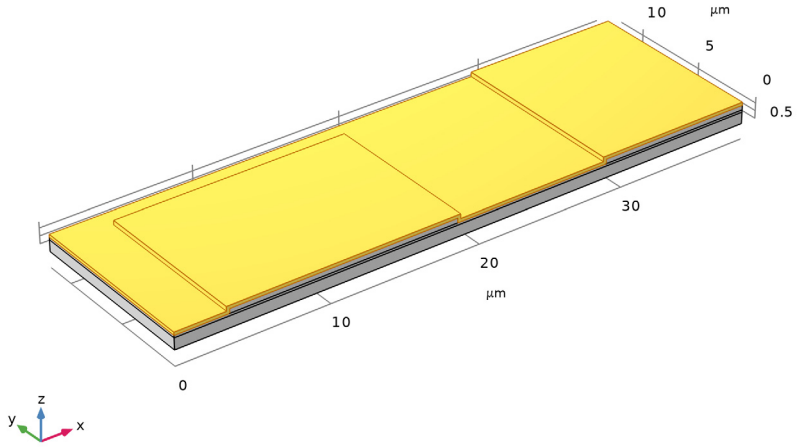
5 Locate the **Offset** section. In the **Distance** text field, type `t_sl`.

6 Locate the **Selections of Resulting Entities** section. Select the **Resulting objects selection** checkbox.

7 From the **Show in physics** list, choose **All levels**.

8 Locate the **Selections on Input Objects** section. Clear the **Propagate selections to resulting objects** checkbox.

9 Click **Build Selected**.



Next, import the mask for the sacrificial layer, which is Layer 5 in the GDS file.

Import 5 = L5, Sacrificial Layer Mask

1 In the **Model Builder** window, under **Component 1 (comp1)** > **Geometry 1** right-click **Import 4 = L4, Deposit and Pattern Bottom Electrode Layer (imp4)** and choose **Duplicate**.

2 In the **Settings** window for **Import**, type `Import 5 = L5, Sacrificial Layer Mask` in the **Label** text field.

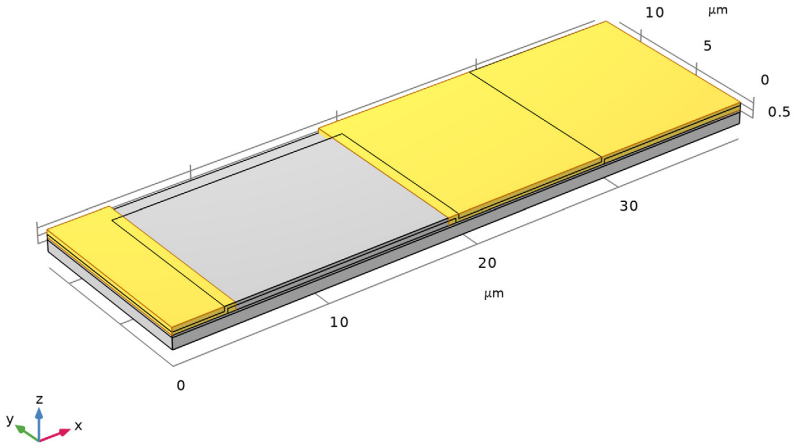
3 Locate the **Layers** section. In the table, enter the following settings:

Name	Type	Thickness (μm)	Elevation (μm)	Import
LAYER32	Metal	`t_base`	`t_sub+t_nitride`	
LAYER40	Metal	`t_base+t_sl`	`t_sub+t_nitride`	√

4 Click to expand the **Selections of Resulting Entities** section. Select the **Resulting objects selection** checkbox.

5 From the **Show in physics** list, choose **All levels**.

6 Click **Build Selected**.



Union Selection 2 (unisel2)

1 In the **Geometry** toolbar, click **Selections** and choose **Union Selection**.

2 In the **Settings** window for **Union Selection**, locate the **Geometric Entity Level** section.

3 From the **Level** list, choose **Object**.

4 Locate the **Input Entities** section. Click **Add**.

5 In the **Add** dialog, in the **Selections to add** list, choose **Offset Faces 1 - Deposit Sacrificial Layer** and **Import 5 = L5, Sacrificial Layer Mask**.

6 Click **OK**.

Intersection 1 = Pattern Sacrificial Layer

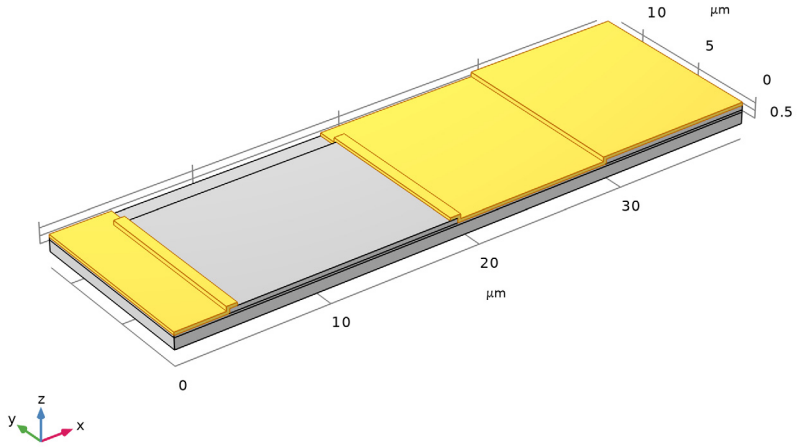
To create the patterned sacrificial layer, intersect the extruded mask layer, resulting from **Import 5**. This step emulates the sacrificial layer etch followed by a photoresist strip.

1 In the **Geometry** toolbar, click **Booleans and Partitions** and choose **Intersection**.

2 In the **Settings** window for **Intersection**, type `Intersection 1 = Pattern Sacrificial Layer` in the **Label** text field.

3 Locate the **Intersection** section. From the **Input objects** list, choose **Union Selection 2**.

4 Click **Build Selected**.



The layer for the polysilicon beam is patterned and deposited over the sacrificial layer, and the exposed faces of the polysilicon base and nitride layers. To create this layer apply the same steps as when creating the sacrificial layer. Continue with offsetting the top faces of the sacrificial, polysilicon base and nitride layers.

Union Selection 3 (unisel3)

1 In the **Geometry** toolbar, click **Selections** and choose **Union Selection**.

2 In the **Settings** window for **Union Selection**, locate the **Geometric Entity Level** section.

3 From the **Level** list, choose **Object**.

4 Locate the **Input Entities** section. Click **Add**.

5 In the **Add** dialog, in the **Selections to add** list, choose **LAYER20 (Import 2 = L2, Deposit Nitride Layer)**, **LAYER31 (Import 3 = L3, Deposit and Pattern Base Layer)**, **LAYER32 (Import 4 = L4, Deposit and Pattern Bottom Electrode Layer)**, **Union Selection 1**, **Union 1**, **Offset Faces 1 - Deposit Sacrificial Layer**, **Import 5 = L5, Sacrificial Layer Mask**, **LAYER40 (Import 5 = L5, Sacrificial Layer Mask)**, and **Union Selection 2**.

6 Click **OK**.

Union 2 (uni2)

1 In the **Geometry** toolbar, click **Booleans and Partitions** and choose **Union**.

2 In the **Settings** window for **Union**, locate the **Union** section.

3 From the **Input objects** list, choose **Union Selection 3**.

4 Select the **Keep input objects** checkbox.

5 Clear the **Keep interior boundaries** checkbox.

6 Locate the **Selections of Resulting Entities** section. Select the **Resulting objects selection** checkbox.

7 Locate the **Selections on Input Objects** section. Clear the **Propagate selections to resulting objects** checkbox.

Box Selection 2 (boxsel2)

1 In the **Geometry** toolbar, click **Selections** and choose **Box Selection**.

2 In the **Settings** window for **Box Selection**, locate the **Geometric Entity Level** section.

3 From the **Level** list, choose **Boundary**.

4 Locate the **Input Entities** section. From the **Entities** list, choose **From selections**.

5 Click **Add**.

6 In the **Add** dialog, select **Union 2** in the **Selections** list.

7 Click **OK**.

8 In the **Settings** window for **Box Selection**, locate the **Box Limits** section.

9 In the **z minimum** text field, type `t_sub+t_nitride+t_base+t_sl-0.01`.

10 In the **z maximum** text field, type `t_sub+t_nitride+t_base+t_sl+0.01`.

11 Locate the **Output Entities** section. From the **Include entity if** list, choose **Entity inside box**.

12 Locate the **Resulting Selection** section. Find the **Cumulative selection** subsection. Click **New**.

13 In the **New Cumulative Selection** dialog, type `Surface Polysilicon Deposition` in the **Name** text field.

14 Click **OK**.

Box Selection 3 (boxsel3)

1 Right-click **Box Selection 2 (boxsel2)** and choose **Duplicate**.

2 In the **Settings** window for **Box Selection**, locate the **Box Limits** section.

3 In the **z minimum** text field, type `t_sub+t_nitride-0.01`.

4 In the **z maximum** text field, type `t_sub+t_nitride+0.01`.

5 Click **Build Selected**.

Box Selection 4 (boxsel4)

1 Right-click **Box Selection 3 (boxsel3)** and choose **Duplicate**.

2 In the **Settings** window for **Box Selection**, locate the **Box Limits** section.

3 In the **z minimum** text field, type `t_sub+t_nitride+t_sl-0.01`.

4 In the **z maximum** text field, type `t_sub+t_nitride+t_base+0.01`.

5 Click **Build Selected**.

Offset Faces 2 - Deposit Polysilicon Layer

1 In the **Geometry** toolbar, click **Editing** and choose **Offset Faces**.

2 In the **Settings** window for **Offset Faces**, type `Offset Faces 2 - Deposit Polysilicon Layer` in the **Label** text field.

3 Locate the **Faces** section. Select the **Subtract input objects** checkbox.

4 Locate the **Offset** section. In the **Distance** text field, type `t_poly`.

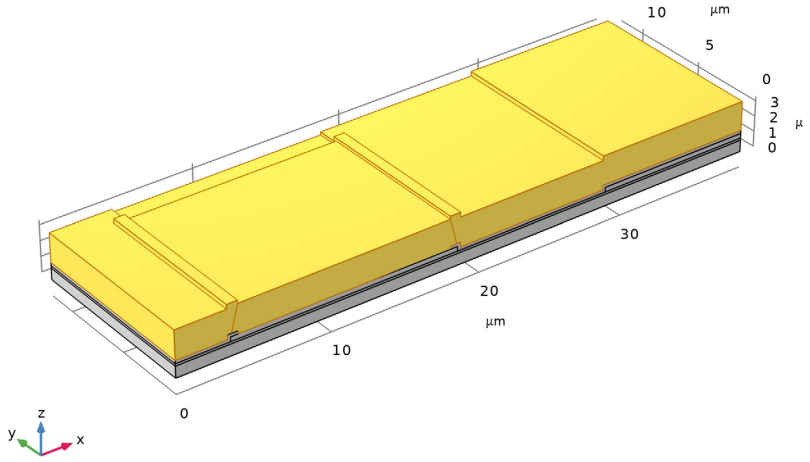
5 Locate the **Options** section. Select the **Perpendicular step edges for surface objects** checkbox.

6 Locate the **Selections of Resulting Entities** section. Select the **Resulting objects selection** checkbox.

7 Find the **Cumulative selection** subsection. From the **Contribute to** list, choose **Polysilicon Beam**.

8 Locate the **Faces** section. From the **Faces to offset** list, choose **Surface Polysilicon Deposition**.

9 Click **Build Selected**.



Import 6 = L6, Polysilicon Layer Mask

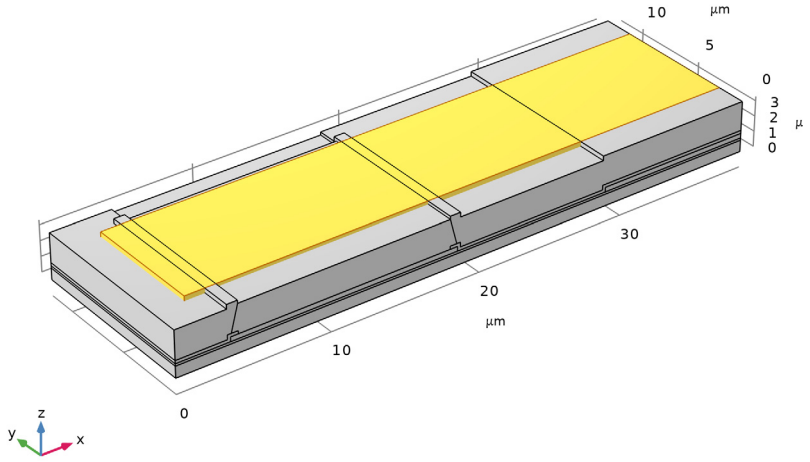
1 In the **Model Builder** window, under **Component 1 (comp1)** > **Geometry 1** right-click **Import 5 = L5, Sacrificial Layer Mask (imp5)** and choose **Duplicate**.

2 In the **Settings** window for **Import**, type `Import 6 = L6, Polysilicon Layer Mask` in the **Label** text field.

3 Locate the **Layers** section. In the table, enter the following settings:

Name	Type	Thickness (µm)	Elevation (µm)	Import
LAYER40	Metal	`t_base+t_sl`	`t_sub+t_nitride`	
LAYER50	Metal	`t_base+t_sl+t_poly`	`t_sub+t_nitride`	√

4 Click **Build Selected**.



Union Selection 4 (unisel4)

1 In the **Geometry** toolbar, click **Selections** and choose **Union Selection**.

2 In the **Settings** window for **Union Selection**, locate the **Geometric Entity Level** section.

3 From the **Level** list, choose **Object**.

4 Locate the **Input Entities** section. Click **Add**.

5 In the **Add** dialog, in the **Selections to add** list, choose **Offset Faces 2 - Deposit Polysilicon Layer** and **Import 6 = L6, Polysilicon Layer Mask**.

6 Click **OK**.

Intersection 2 = Pattern Polysilicon Layer

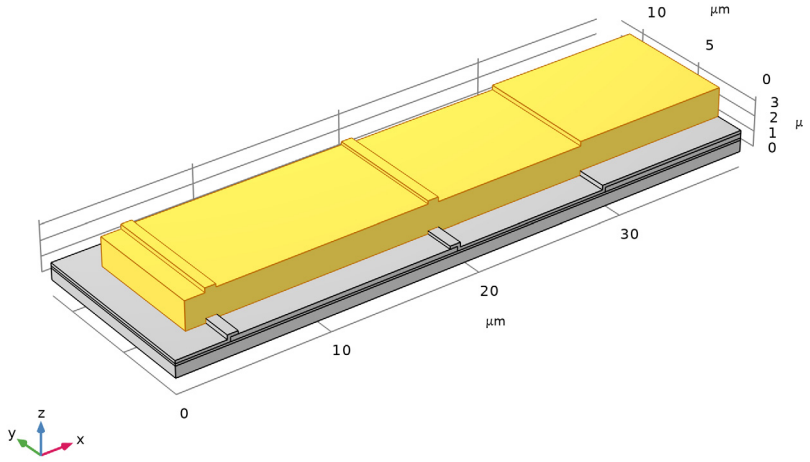
1 In the **Geometry** toolbar, click **Booleans and Partitions** and choose **Intersection**.

2 In the **Settings** window for **Intersection**, type `Intersection 2 = Pattern Polysilicon Layer` in the **Label** text field.

3 Locate the **Intersection** section. From the **Input objects** list, choose **Union Selection 4**.

4 Locate the **Selections of Resulting Entities** section. Find the **Cumulative selection** subsection. From the **Contribute to** list, choose **Polysilicon Beam**.

5 Click **Build Selected**.



To obtain the final geometry, delete the object for the sacrificial layer. This step emulates an isotropic oxide etch to release the polysilicon beam.

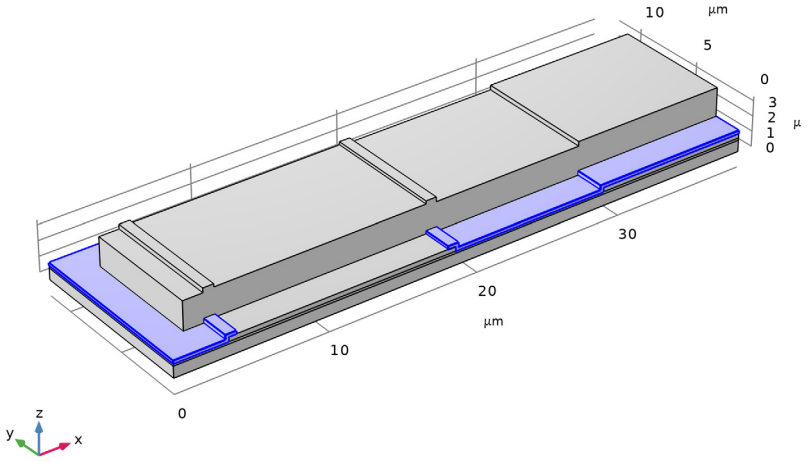
Delete Entities 1 (del1)

1 In the **Model Builder** window, right-click **Geometry 1** and choose **Delete Entities**.

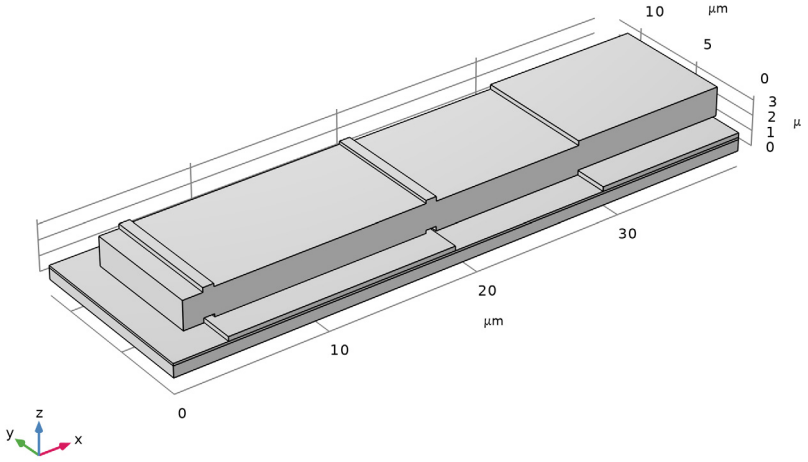
2 In the **Settings** window for **Delete Entities**, locate the **Entities or Objects to Delete** section.

3 From the **Geometric entity level** list, choose **Object**.

4 Select the object **int1** only.



5 Click **Build Selected**.



Mirror 1 (mir1)

1 In the **Geometry** toolbar, click **Transforms** and choose **Mirror**.

2 Click the **Select Box** button in the **Graphics** toolbar.

3 Click in the **Graphics** window and then press Ctrl+A to select all objects.

4 In the **Settings** window for **Mirror**, locate the **Point on Plane of Reflection** section.

5 In the **x** text field, type `w_box`.

6 Locate the **Normal Vector to Plane of Reflection** section. In the **x** text field, type `1`.

7 In the **z** text field, type `0`.

8 Click **Build Selected**.

9 Locate the **Input** section. Select the **Keep input objects** checkbox.

10 Click **Build Selected**.

ADD MATERIAL

1 In the **Materials** toolbar, click **Add Material** to open the **Add Material** window.

2 Go to the **Add Material** window.

3 In the tree, select **MEMS** > **Semiconductors** > **Si - Polycrystalline silicon**.

4 Click the **Add to Component** button in the window toolbar.

5 In the tree, select **MEMS** > **Insulators** > **Si3N4 - Silicon nitride**.

6 Click the **Add to Component** button in the window toolbar.

7 In the tree, select **MEMS** > **Insulators** > **SiO2 - Silicon oxide**.

8 Click the **Add to Component** button in the window toolbar.

9 In the **Materials** toolbar, click **Add Material** to close the **Add Material** window.

MATERIALS

Si3N4 - Silicon nitride (mat2)

1 In the **Settings** window for **Material**, locate the **Geometric Entity Selection** section.

2 From the **Selection** list, choose **Nitride**.

SiO2 - Silicon oxide (mat3)

1 In the **Model Builder** window, click **SiO2 - Silicon oxide (mat3)**.

2 In the **Settings** window for **Material**, locate the **Geometric Entity Selection** section.

3 From the **Selection** list, choose **Substrate**.

SOLID MECHANICS (SOLID)

1 In the **Model Builder** window, under **Component 1 (comp1)** click **Solid Mechanics (solid)**.

2 Select Domains 3, 4, 9, and 10 only.

Fixed Constraint 1

1 In the **Physics** toolbar, click **Domains** and choose **Fixed Constraint**.

2 Select Domains 4 and 10 only.

MESH 1

1 In the **Model Builder** window, under **Component 1 (comp1)** click **Mesh 1**.

2 In the **Settings** window for **Mesh**, locate the **Physics-Controlled Mesh** section.

3 From the **Element size** list, choose **Coarser**.

4 Click **Build All**.

STUDY 1

Step 1: Eigenfrequency

1 In the **Model Builder** window, under **Study 1** click **Step 1: Eigenfrequency**.

2 In the **Settings** window for **Eigenfrequency**, locate the **Study Settings** section.

3 Select the **Desired number of eigenfrequencies** checkbox. In the associated text field, type 3.

4 In the **Study** toolbar, click **Compute**.

RESULTS

Mode Shape (solid)

In the **Model Builder** window, expand the **Mode Shape (solid)** node.

Surface 1

1 Click the **Zoom Extents** button in the **Graphics** toolbar.

2 In the **Model Builder** window, expand the **Results** > **Mode Shape (solid)** > **Surface 1** node, then click **Surface 1**.

3 In the **Settings** window for **Surface**, click **Plot Next**.

4 Click **Plot Next**.