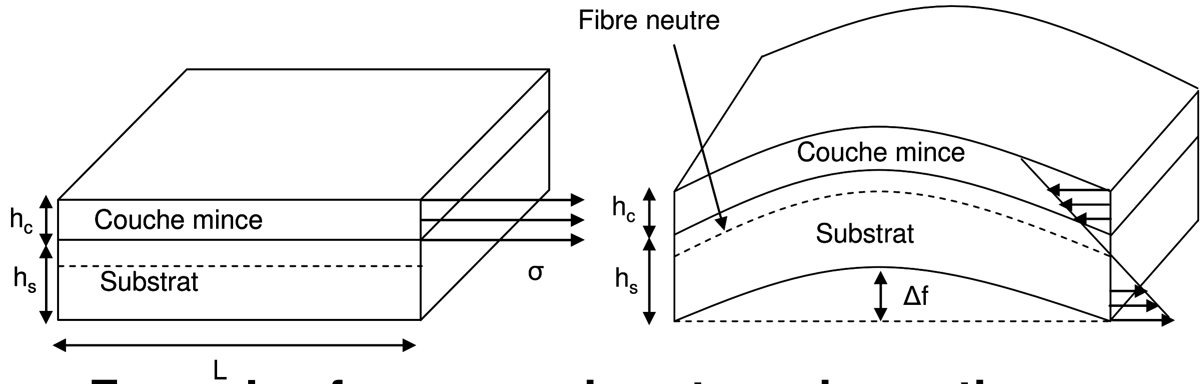
On feasibility of mechanically-induced transitions between quantum states

Stress in the coatings

Substrate temperature, deposition rate, deposition energy, microstructure, and environment all influence the intrinsic stress that a thin film experiences. The stress value generally increases with film thickness, but there are exceptions to this behavior. Thermal expansion coefficient differences influence the extrinsic stress value. Intrinsic stress that is tensive exerts a contraction force parallel to the substrate surface and can result in a concave curvature. The opposite is observed with compressive stresses that produce convex curvature of the coated substrate. Visible signs of the release of tensive stress are "mud flat" patterns where irregular pieces of the coating crack apart and might curl concavely with the edges lifted from the substrate. A film whose compressive stress force exceeds the bond to the substrate will delaminate from the substrate surface.

It is important to note that the stress measured in our coating is the result of :
- Intrinsic stress due to the arrangement of the atoms during the growing process
- Thermic stress, appearing when the component reaches the room temperature, due to the difference in the thermal expansion coefficient between substrate and layers
- Stress at the interface due to the way of growing



Sag = Δf

Example of compressive stress in coatings

One approach is to bombard the growing film with energetic particles, either inert argon or reactive oxygen (or mixtures of both). The energy dissipated in the microstructure in effect breaks up the columnar crystalline growth tendency and can change tensive to compressive stress and even balance the resultant stress to zero.

Deformation of substrate under the coating stress

Simulation of the déformation of silica substrate due to the stress of a thin layer of Carbon

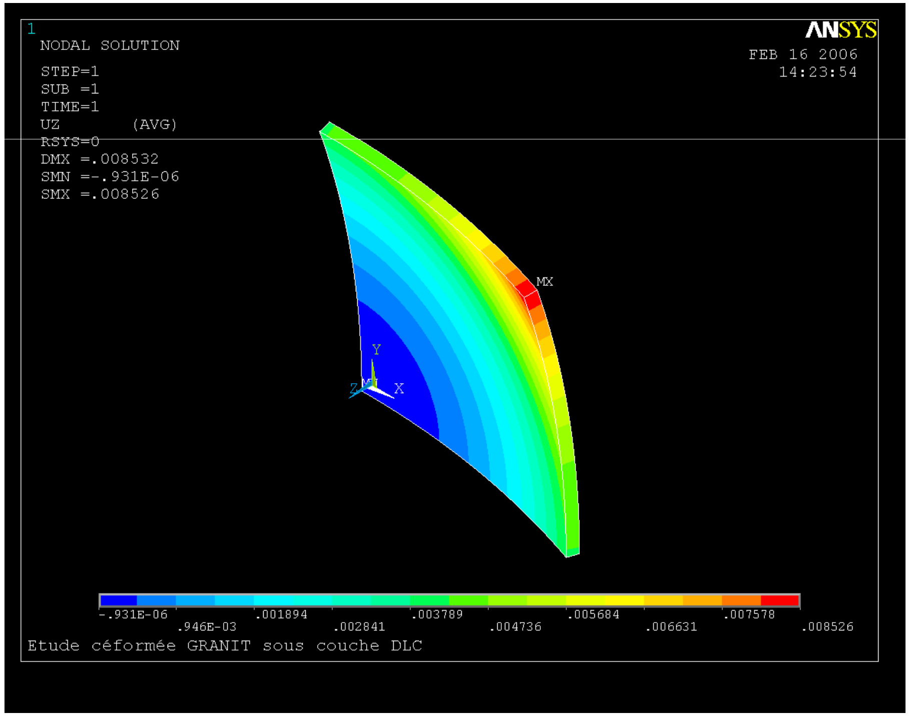
Présentation du problème :

- We have deposited 200 nm of IBS Carbon on a square silica substrate of 50 X 50 mm. The layers of Carbon induce compressive intrinsic stresses of 1 GPa. The substrate is bended by the layer in a higher proportion if the substrate is thinner

-The simulation is calculated by finite element calculation (FEA) using the software ANSYS 9.0.

-In our calculation, we have supposed different thickness of the substrate and we have calculation the total strain induced by the layer

In the plot below, we give the result of the deformation of a substrate of 1 mm thick. We visualize only a quarter of the substrate because the model is symmetric and it is important to gain in time of calculation

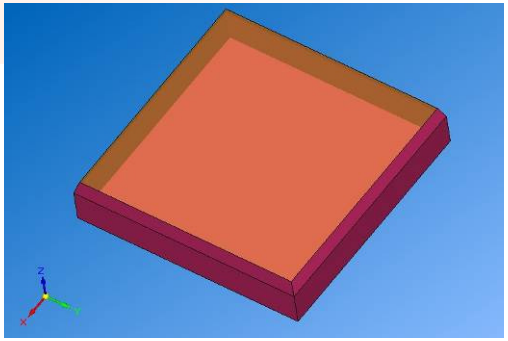


	Layer of 200 nm of IBS carbon
Substrate thickness : 1 mm	Sag : **8,5 µm**
Substrate thickness : 5 mm	Sag : **0,350 µm**
Substrate thickness : 10 mm	Sag : **0 ,098 µm**

Table summarizing the different strains obtained

NB : For very thin substrate (1 mm), the FEA simulation is in total adequation with analytical calculation and the formula of STONEY.

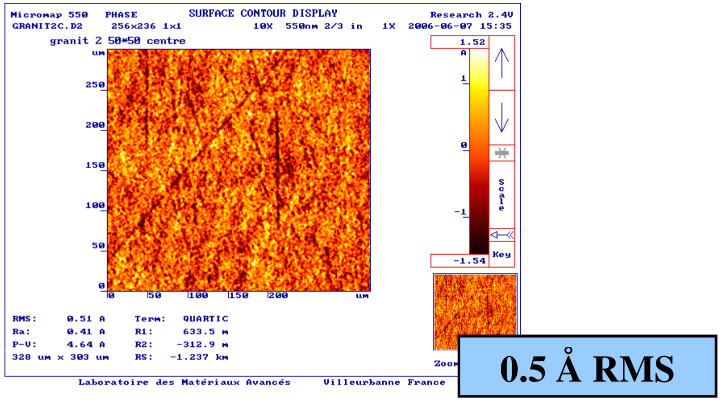
Experimental results : substrate roughness



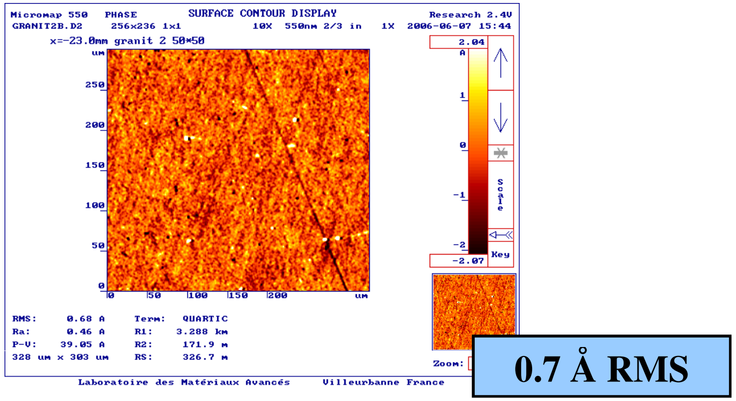
We have coated 2 silica substrates of 50 mm X 50 mm X 10 mm

With 200 nm IBS carbon

Micromap measurements before coating

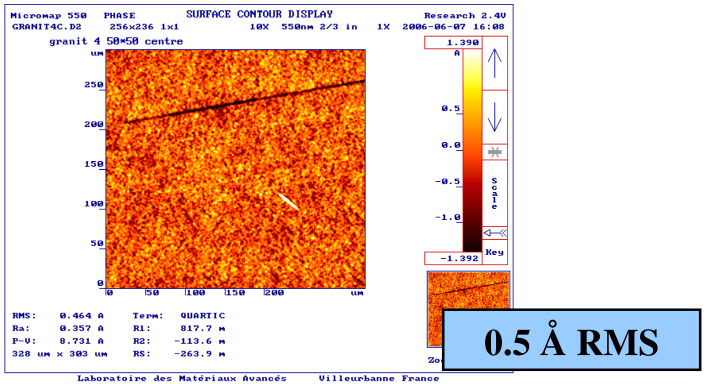


Substrate at centre

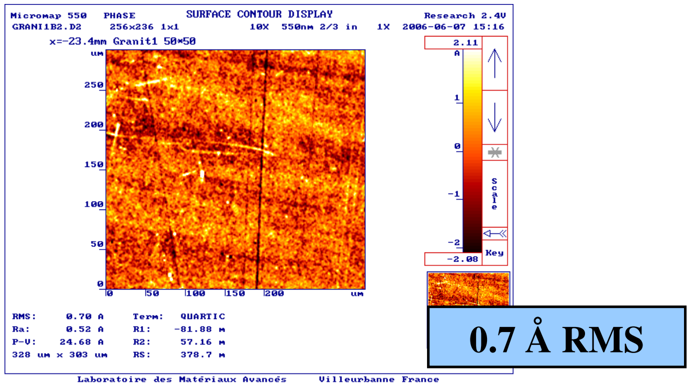


Substrate at the edge

Micromap measurements after coating

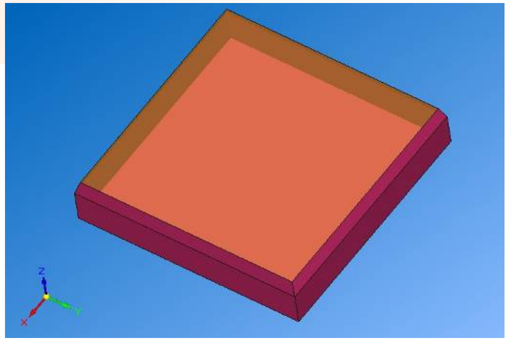


200 nm carbon on substrate



200 nm carbon on substrate

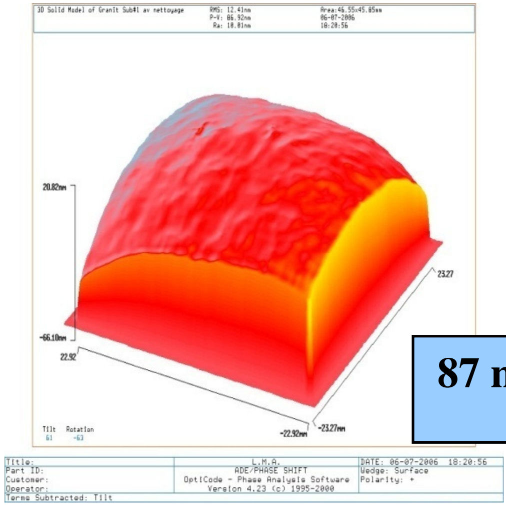
Experimental results : substrate flatness



We have coated 2 silica substrates of 50 mm X 50 mm X 10 mm

With 200 nm IBS carbon

PHASESHIFT measurements before coating

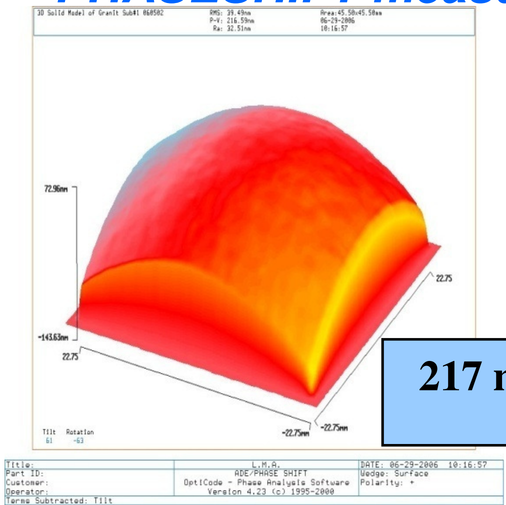


Area measured : 45 X 45 mm²

Substrate uncoated

87 nm PTV

PHASESHIFT measurements after coating



200 nm carbon on substrate

217 nm PTV

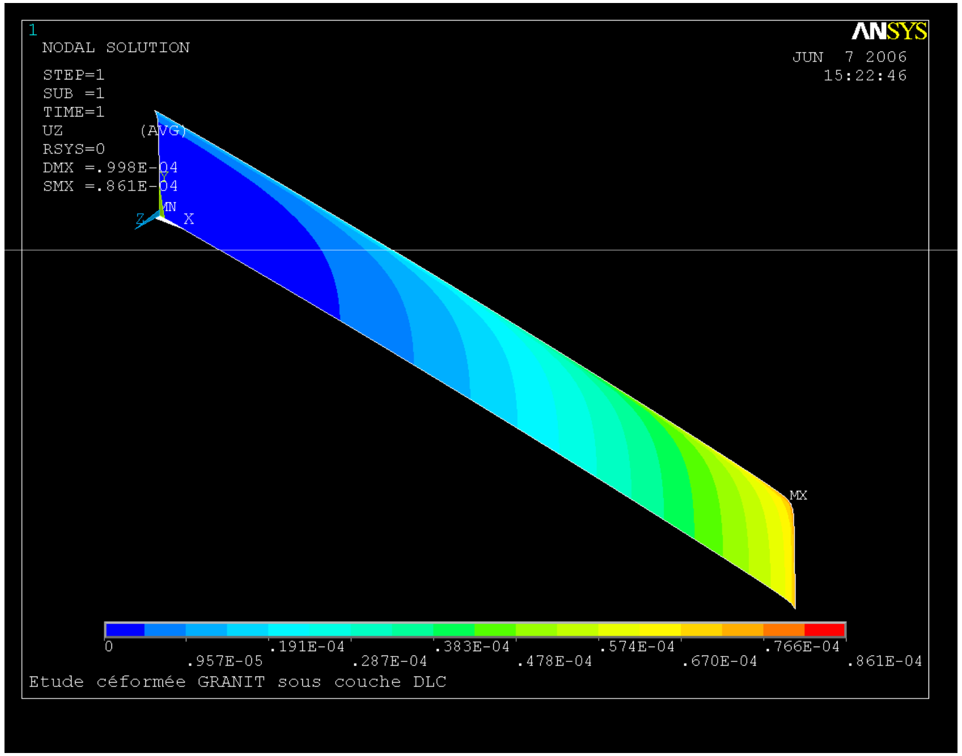
The measurement is in complete agreement with the FEA calculation but confirm a compressive stress of 2 GPa (1 GPa for CVD Carbon (DLC))

Deformation of substrate under the coating stress

We have achieved the same kind of FEA calculation but with a geometry close to the final geometry for the wall of the trap

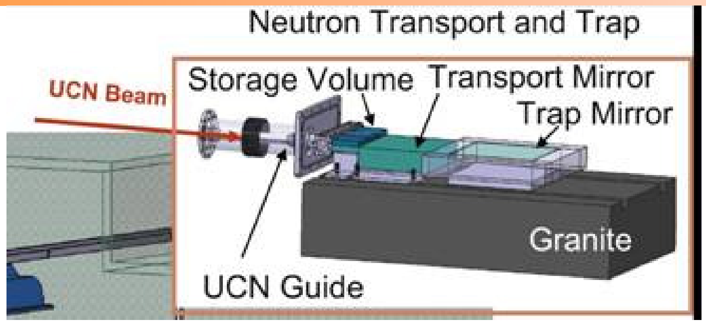
-The substrate geometry is 300 mm X 40 mm and we have varied the thickness from 10 mm to 50 mm

-The compressive stress admitted is 1 GPa



	Layer of 200 nm of IBS carbon
Substrate thickness : 10 mm	Sag : **1,58 µm**
Substrate thickness : 20 mm	Sag : **0,410 µm**
Substrate thickness : 30 mm	Sag : **0 ,194 µm**
Substrate thickness : 40 mm	Sag : **0 ,120 µm**
Substrate thickness : 50 mm	Sag : **0 ,086 µm**

Table summarizing the different strains obtained



Goal : vibrate with piezo-electric actuators the Silica ground mirror of the trap at transition frequencies

Frequencies for the GRANIT experiment

For the very first ten quantum states the transition frequencies in Hz are presented in the following table:

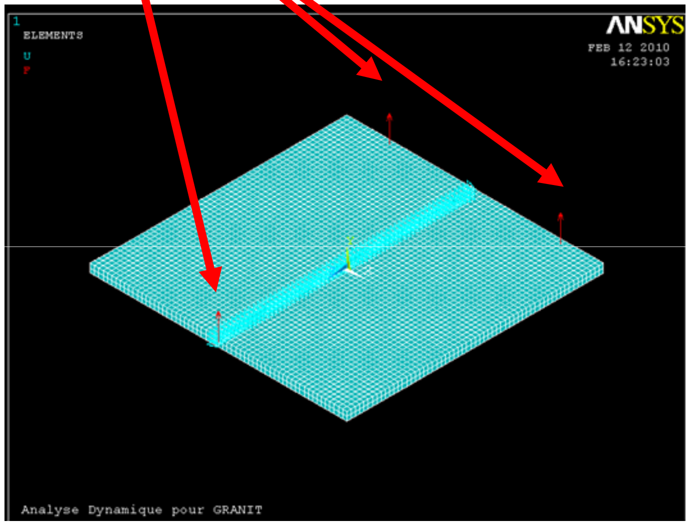
initial/final quantum number	1	2	3	4	5	6	7	8	9	10
1	0	256	465	650	818	975	1123	1264	1399	1529
2	256	0	209	393	562	719	867	1008	1143	1273
3	465	209	0	184	353	510	658	799	934	1064
4	650	393	184	0	168	325	474	614	749	879
5	818	562	353	168	0	157	305	446	581	711
6	975	719	510	325	157	0	148	289	424	554
7	1123	867	658	474	305	148	0	141	276	406
8	1264	1008	799	614	446	289	141	0	135	265
9	1399	1143	934	749	581	424	276	135	0	130
10	1529	1273	1064	879	711	554	406	265	130	0

Courtesy of Konstantin Protassov

mechanically-induced transitions between quantum states : 3 actuators

Ground mirror : 300 mm X 300 mm X 10 mm – FEA meshing size : 5 mm)

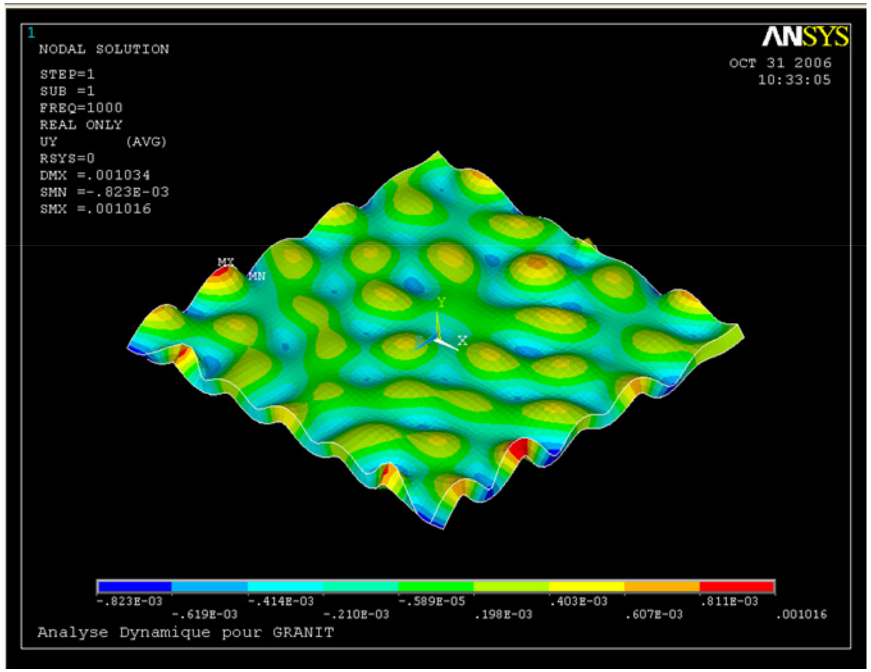
3 punctual piezo-electric actuators bonded to the sides of the mirror



Force/actuators = 100 Newtons * sin (2π.1000 Hz)

Vibration Frequency 1000 Hz

Amplitude of the deformation : 2 µm

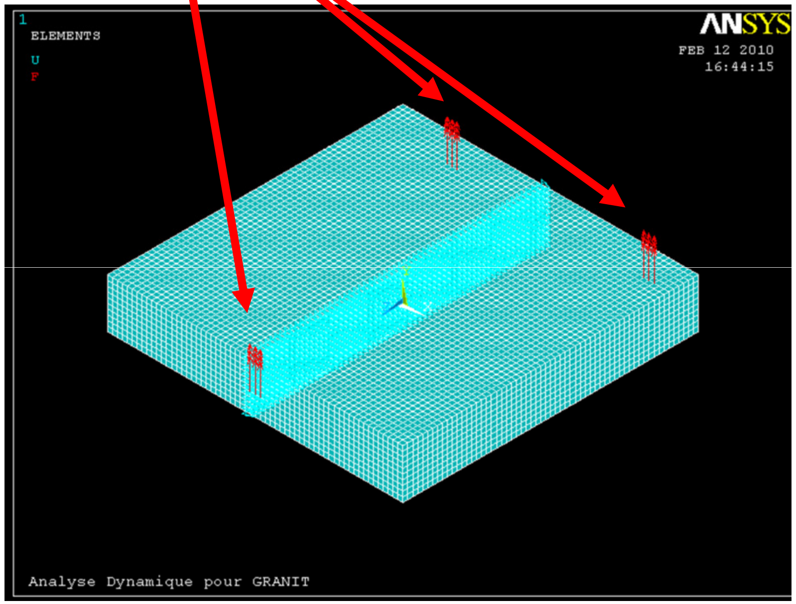


The surface is not flat, it shows deep hollows and bumps

Ground mirror : 300 mm X 300 mm X 50 mm

3 piezo-electric actuators

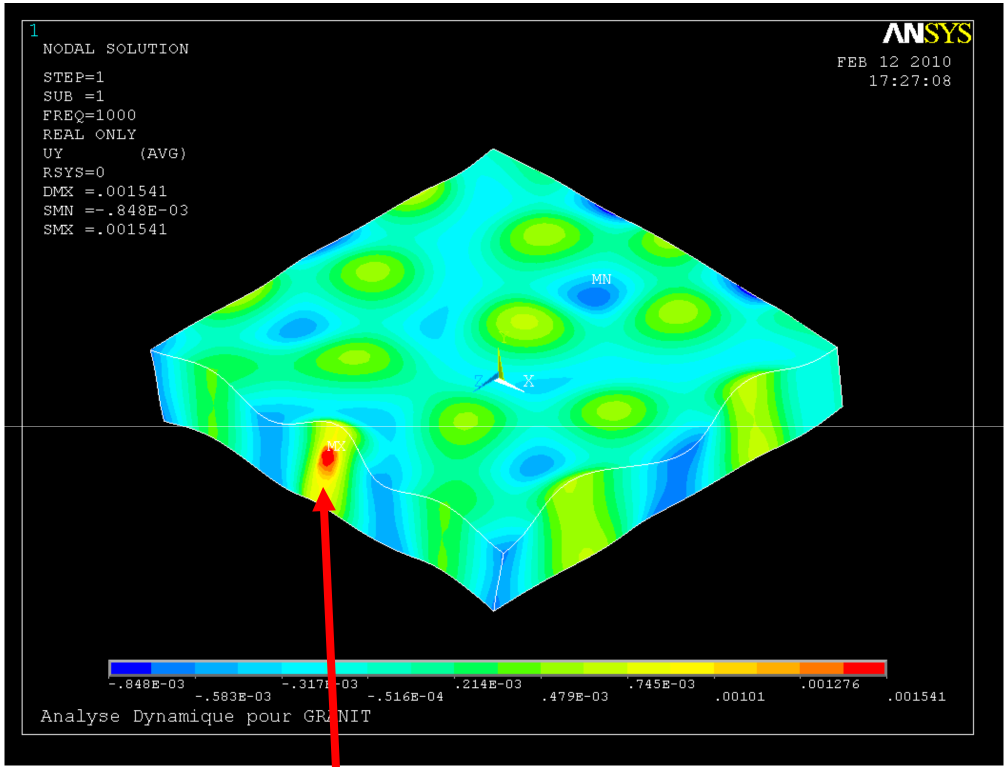
Attached surface : 1 cm²



Force/actuators = 1000 Newtons * sin (2π.1000 Hz)

Vibration Frequency 1000 Hz

Amplitude of the deformation : 2.5 µm



Estimated maximum Von Mises stress about 7 MPa
(< 50 MPa = silica tensive strength)

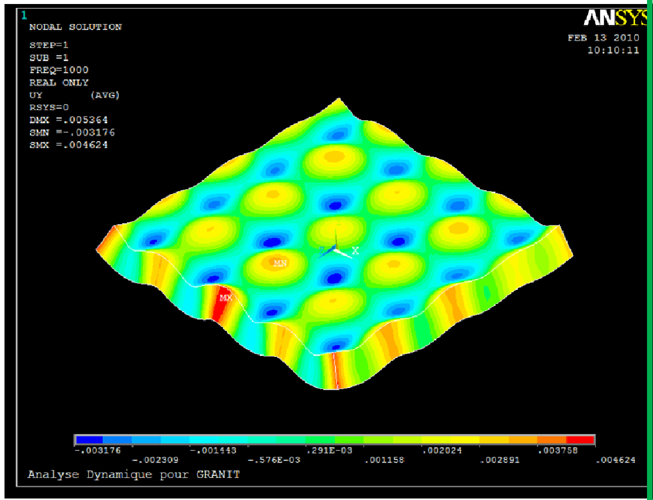
The surface is not flat, it shows deep hollows and bumps
but less nodes compared to the 10 mm thick plate

Ground mirror : 300 mm X 300 mm X 30 mm

3 piezo-electric actuators bonded on the sides of the mirror (linked surface : 1 cm^2)

Frequency : 1000 Hz

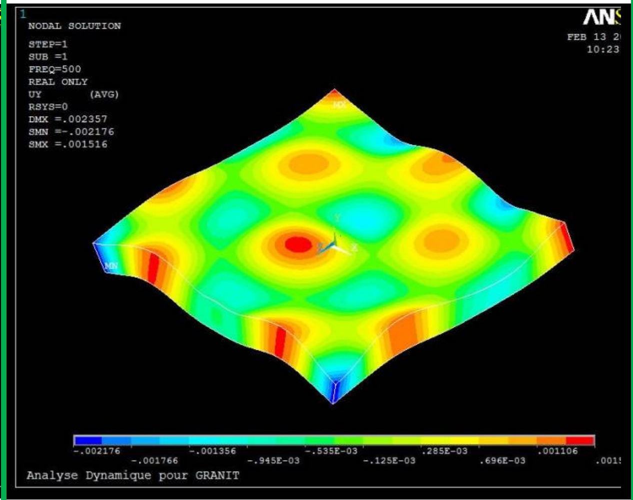
Force/actuators = 450 Newtons * sin ($2\pi.\upsilon$ Hz)



Surface Deformation : 6 µm

Frequency : 500 Hz

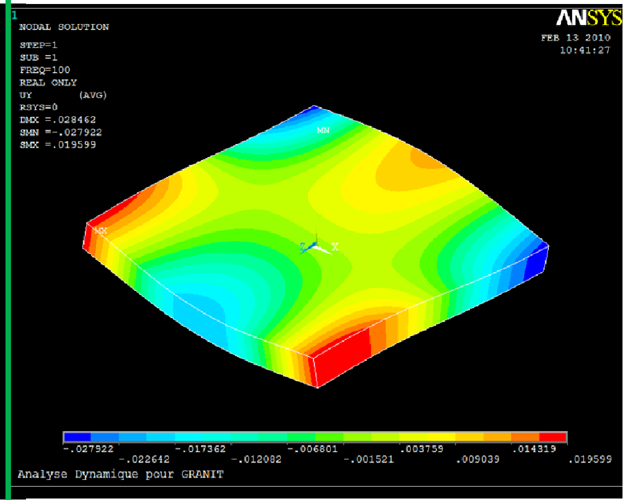
Force/actuators = 450 Newtons * sin ($2\pi.\upsilon$ Hz)



Surface Deformation : 3 µm

Frequency : 100 Hz

Force/actuators = 45 Newtons * sin ($2\pi.\upsilon$ Hz)



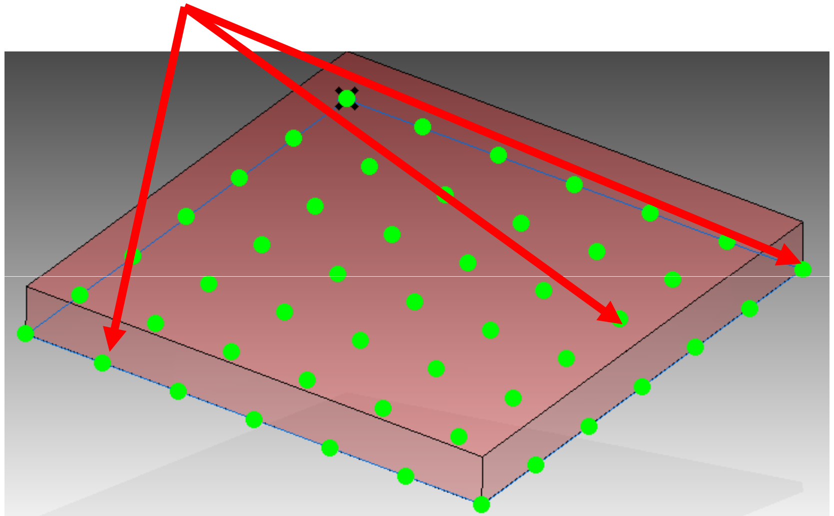
Surface Deformation : 4 µm

- **The surface deformation amplitude is no frequency dependant**
- **The frequency have an influence on the number of nodes and the force needed to move the mirror**

Ground mirror : 300 mm X 300 mm X 30 mm – FEA meshing size : 5 mm)

The problem is symmetrized (CPU time gain)

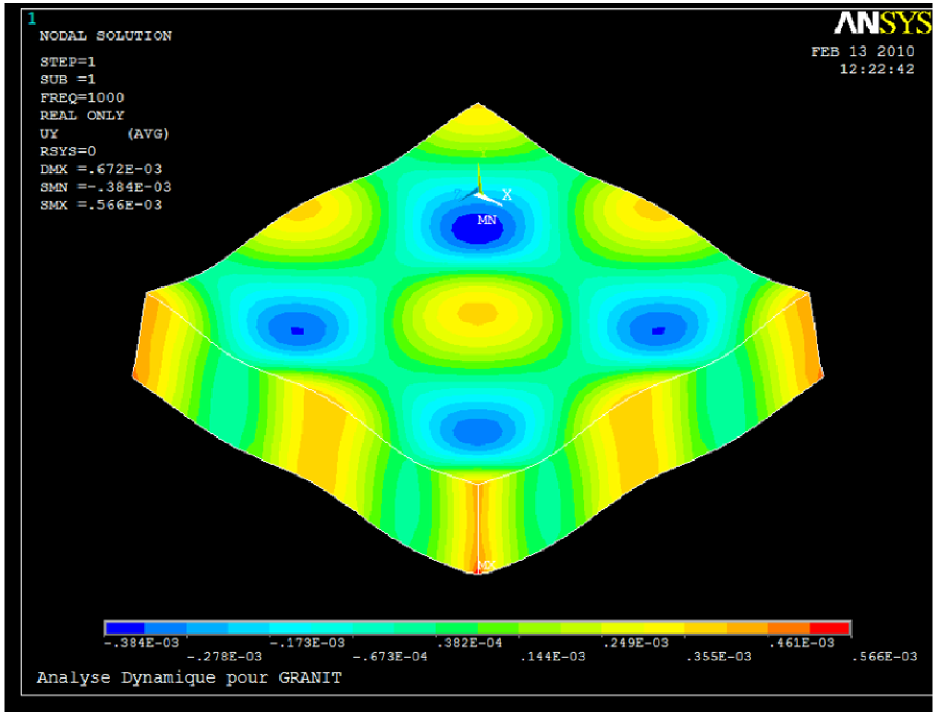
49 punctual piezo-electric actuators bonded to the rear sides of the mirror and spaced every 50 mm



*Force/actuators = 5 Newtons * sin (2π.1000 Hz)*

Vibration Frequency 1000 Hz

Amplitude of the deformation : 1 µm



It is the quarter of the whole mirror

The surface is not flat, it shows the same deep hollows and bumps as for the 3 actuators

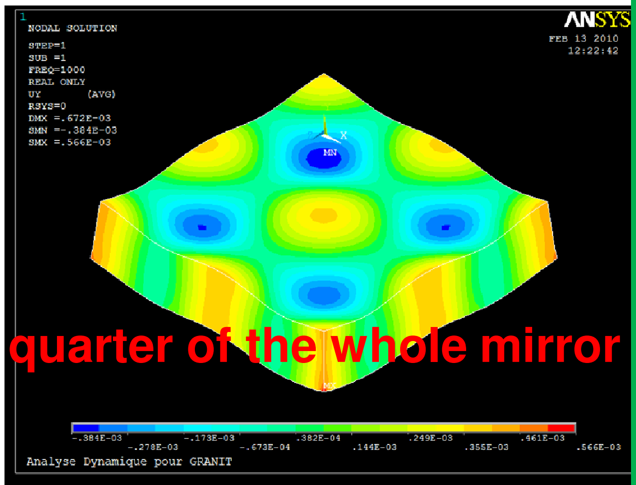
mechanically-induced transitions between quantum states : 49 actuators (frequency dependance)

Ground mirror : 300 mm X 300 mm X 30 mm

49 punctual piezo-electric actuators bonded to the rear sides of the mirror and spaced every 50 mm

Frequency : 1000 Hz

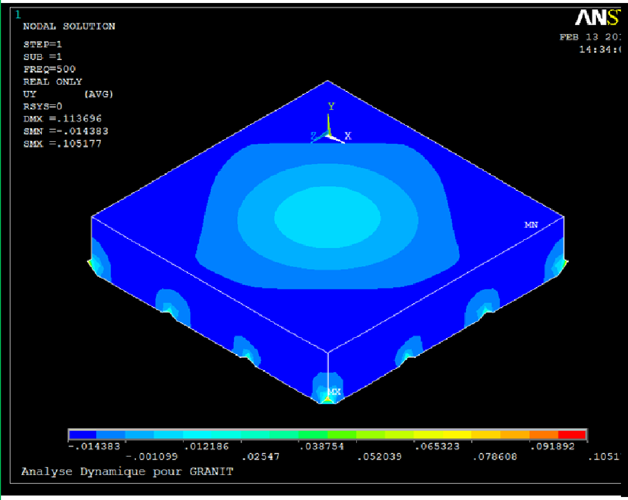
Force/actuators = 5 Newtons * sin (2π.υ Hz) (Total = 250 N)



Surface Deformation : 1 µm

Frequency : 500 Hz

Force/actuators = 5000 Newtons * sin (2π.υ Hz) (Total = 250 000 N)

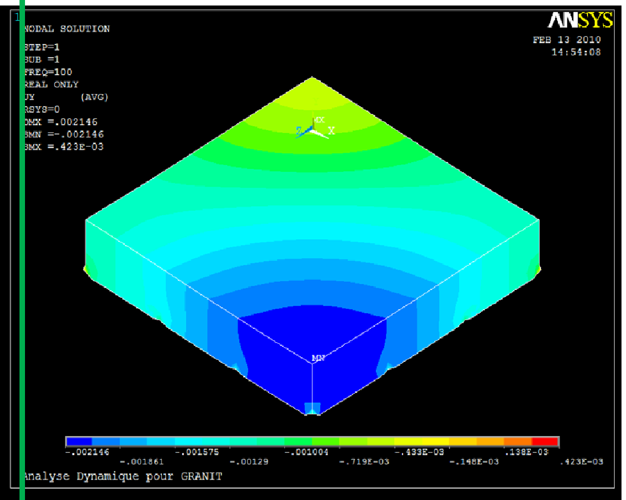


Surface Deformation : 2 µm

(Rear surface deformation > 100 µm)

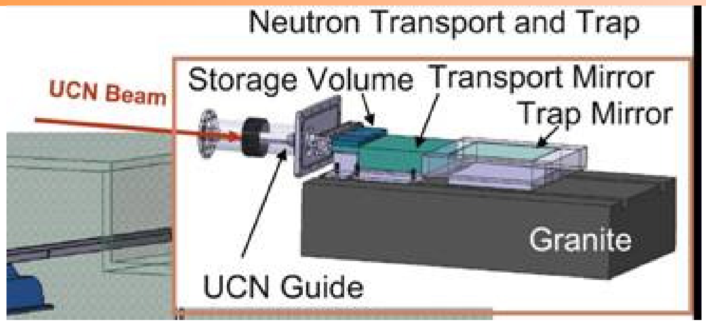
Frequency : 100 Hz

Force/actuators = 45 Newtons * sin (2π.υ Hz)



Surface Deformation : 1 µm

- **The surface deformation amplitude is no frequency dependant**
- **The frequency have an influence on the number of nodes and the force needed to move the mirror**



Goal : vibrate with piezo-electric actuators the ground mirror of the trap at transition frequencies

Two configurations simulated by FEA :
- **3 actuators placed on the sides of the mirror**
- **49 actuators placed on the bottom face of the mirror**

The FEA calculations have shown that for both setup :

@ high frequencies (around 1000 Hz) : high amplitude waves on the top surface.

@ low frequencies (around 100 Hz) : drum mode but same deformation amplitude.

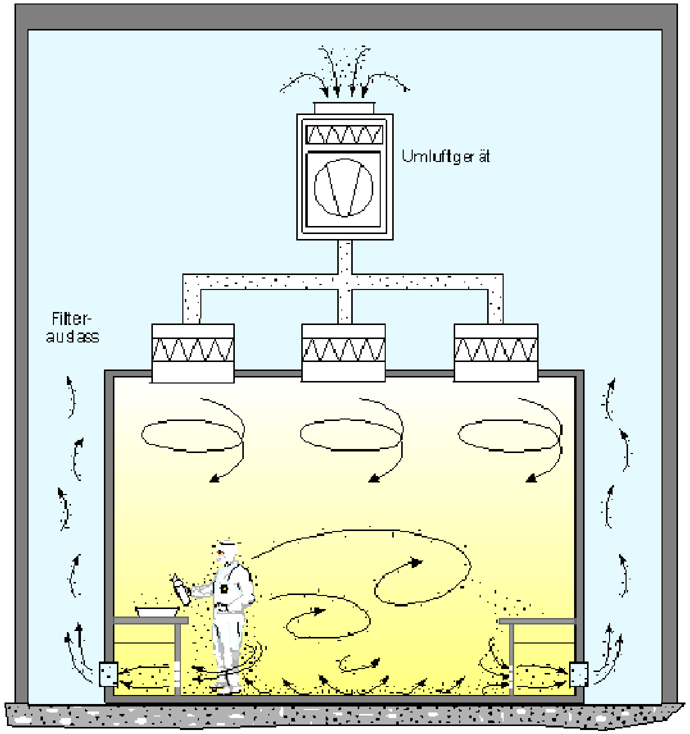
Cleanroom

A **cleanroom is an environment, typically used in** manufacturing or scientific research, that has a low level of environmental pollutants such as dust, airborne microbes, aerosol particles and chemical vapors. More accurately, a cleanroom has a *controlled* level of contamination that is specified by the number of particles per cubic meter at a specified particle size. To give perspective, the ambient air outside in a typical urban environment contains 35,000,000 particles per cubic meter, 0.5 µm and larger in diameter, corresponding to an ISO 9 cleanroom.

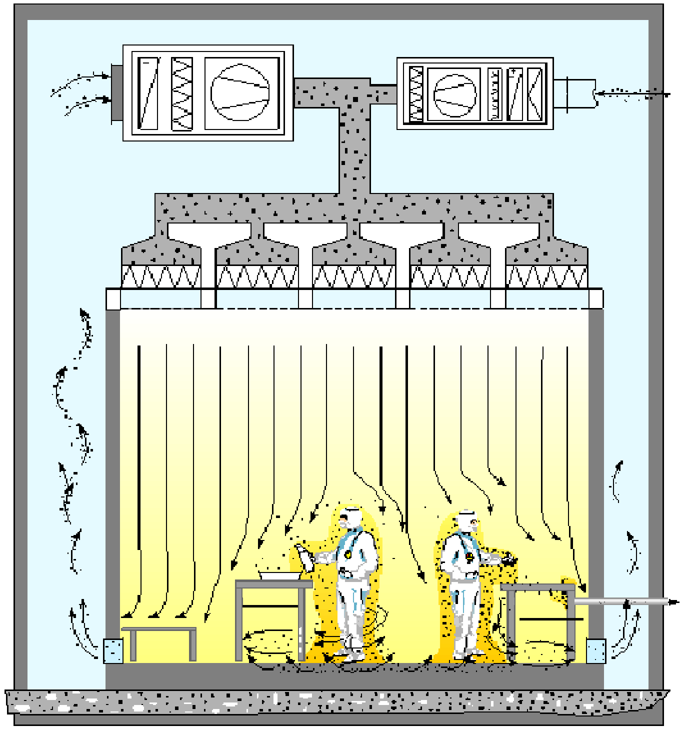
ISO 14644-1 cleanroom standards [edit]

Class	maximum particles/m³						FED STD 209E equivalent
	≥0.1 µm	≥0.2 µm	≥0.3 µm	≥0.5 µm	≥1 µm	≥5 µm	
ISO 1	10	2					
ISO 2	100	24	10	4			
ISO 3	1,000	237	102	35	8		Class 1
ISO 4	10,000	2,370	1,020	352	83		Class 10
ISO 5	100,000	23,700	10,200	3,520	832	29	Class 100
ISO 6	1,000,000	237,000	102,000	35,200	8,320	293	Class 1000
ISO 7				352,000	83,200	2,930	Class 10,000
ISO 8				3,520,000	832,000	29,300	Class 100,000
ISO 9				35,200,000	8,320,000	293,000	Room air

✓ **They are used extensively in semiconductor factory, biotechnology, the life sciences and other fields that are very sensitive to environmental contamination.**
✓ **The air entering a cleanroom from outside is filtered to exclude dust, and the air inside is constantly recirculated through high efficiency particulate air (HEPA) and/or ultra low particulate air (ULPA) filters to remove internally generated contaminants.**



Air flow pattern for "Turbulent Cleanroom"



Air flow pattern for “Laminar Flow Cleanroom"

Cleanroom

✓ Staff enter and leave through airlocks (sometimes including an air shower stage), and wear protective clothing such as hats, face masks, gloves, boots and cover-alls.

Clothes and behavior

Cleanroom paper

Particle counter

✓ Common materials such as paper, pencils, and fabrics made from natural fibers are often excluded; however, alternatives are available.

✓ Particle levels are often tested using a particle counter.

✓ Some cleanrooms are kept at a positive pressure so that if there are any leaks, air leaks out of the chamber instead of unfiltered air coming in.

✓ Some cleanroom HVAC systems control the humidity to low levels, such that extra precautions are necessary to prevent electrostatic discharge (ESD) problems. These ESD controls ("ionizers") are also used in rooms where ESD sensitive products are produced or handled.

✓ never break the cleanliness chain – clean regularly (isopropanol – hoover)

The **LMA cleanroom is few words, figures and photos**

Air treatment : air replacement 600 time/Hour

- 240 m^3/ Hour
- Air speed : 0.5 m/s

Cleanroom : 150 m^2 class ISO 3
HEPA, ULPA and cleanroom filters of the whole ceiling

Under the clean room : cleanroom plenum
Surface : 150 m^2 – Height 4.5 m
Cleanroom walls, special resist on the floor

Cost : 100 k€ / year