Presentation

Nanotubes & Nanostructures 2001

Step bunching design on vicinal Si(111) surface at high temperature.

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Aim of this study

Preparation of a silicon (111) substrate by self-organization.

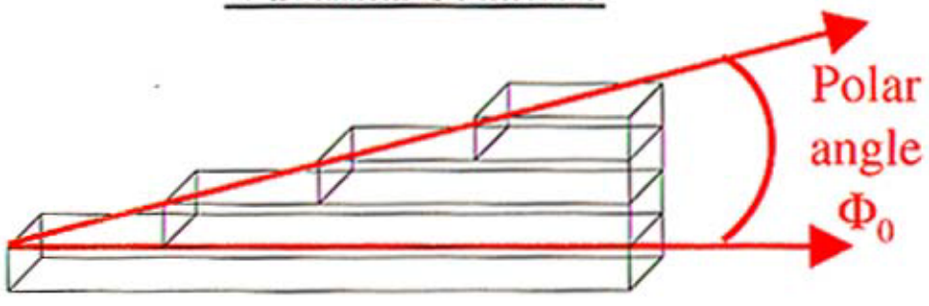
A multivicinal surface with predefined pattern → **Controlled morphology of the final surface**

Application for :

- Self-assembling of nanostructures
- Nanotechnology

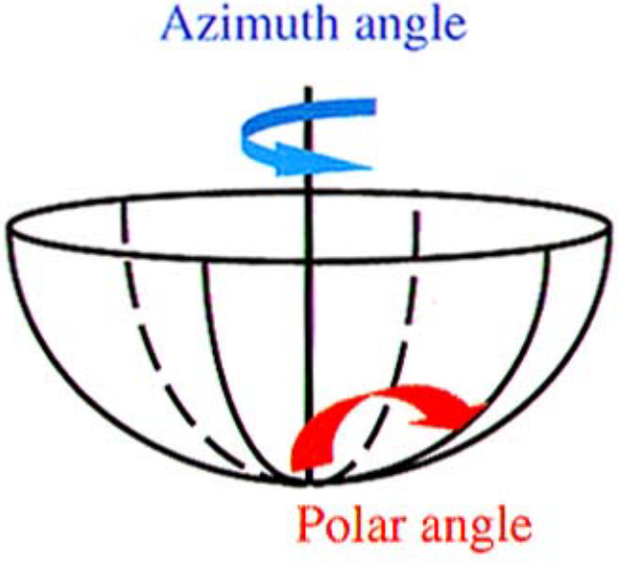
Glossary

Vicinal surface



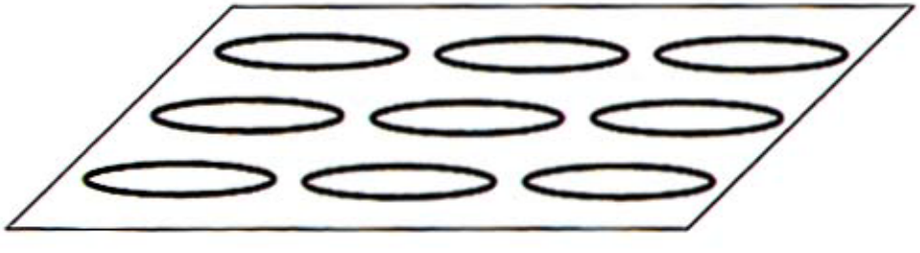
Φ_0 : 1.5°~10°

Azimuth : $[11\bar{2}]$



Multivicinal surface

Array of
multivicinal surfaces

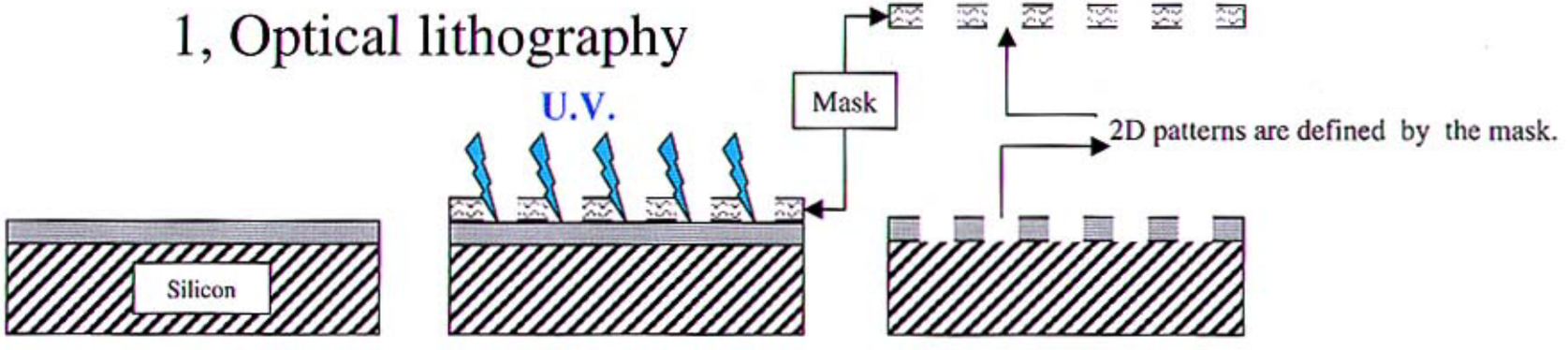


Process

Elaboration

The fabrication is made in 2 stages :

1, Optical lithography



1. Deposit of a thin film resin.

2. U.V. exposure of the photosensitive resin through a mask.

3. Development of the insolated resin.

2, Chemical etching (HNO_3:HF:CH_3COOH)

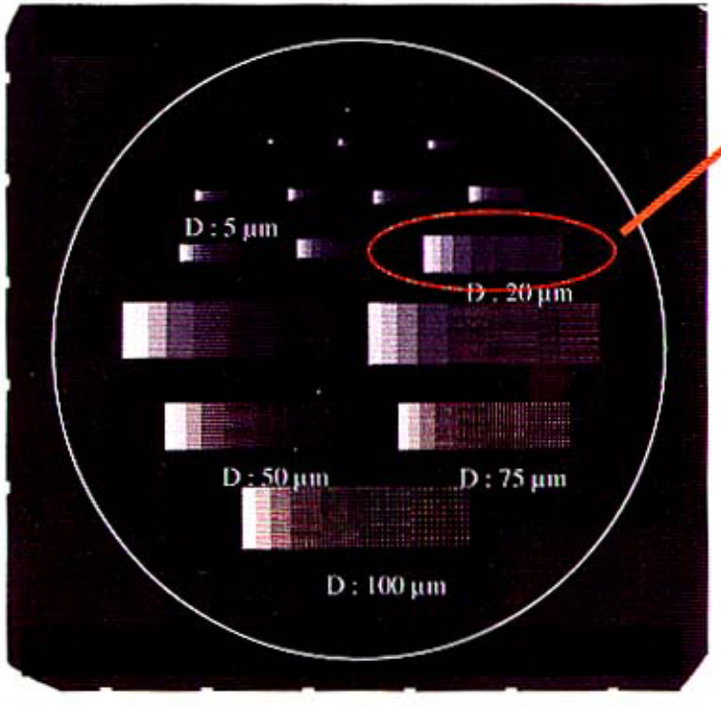
4. By selective etching, an array of holes is patterned in the silicon wafer.

5. Elimination of the remaining resin.

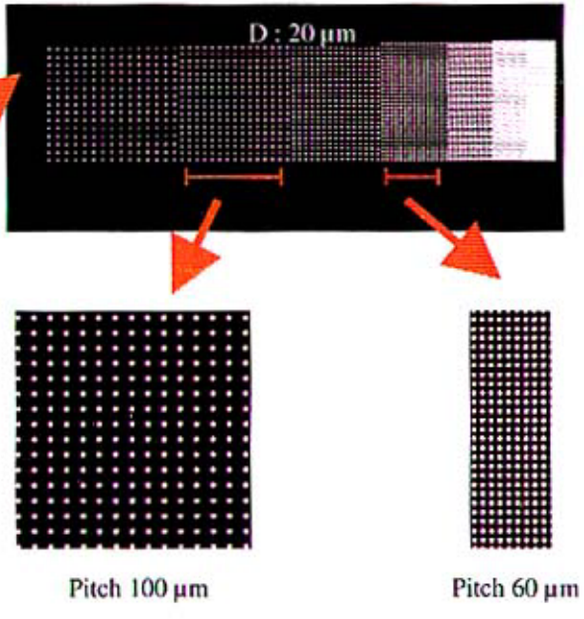
Process

Features design of the mask

The mask used is designed to give specific geometric characteristics :



Zoom on one zone of the mask :



→ Diameter of the holes

→ Pitch of the array

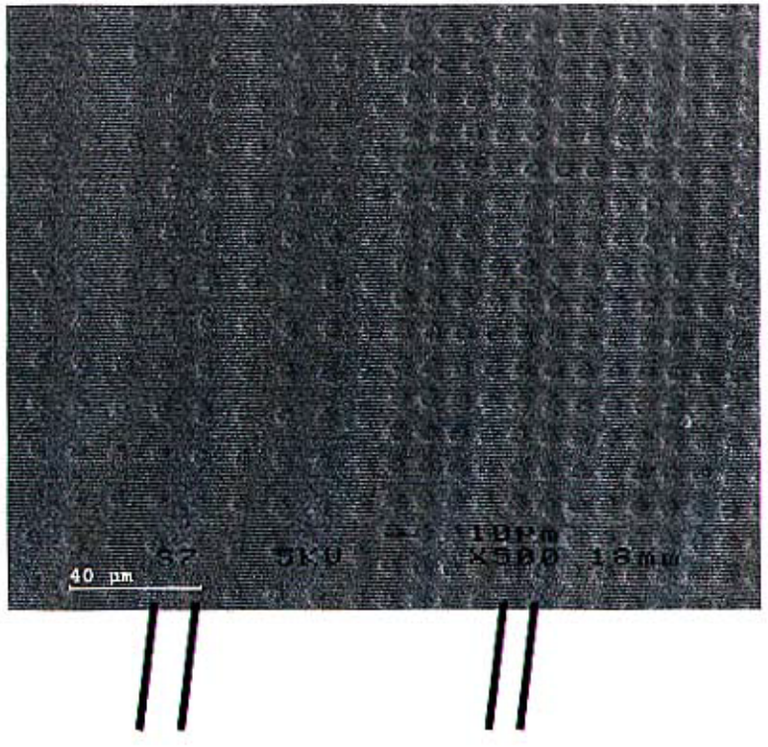
(Pitch : distance between 2 holes)

Preliminary Results

Samples patterning

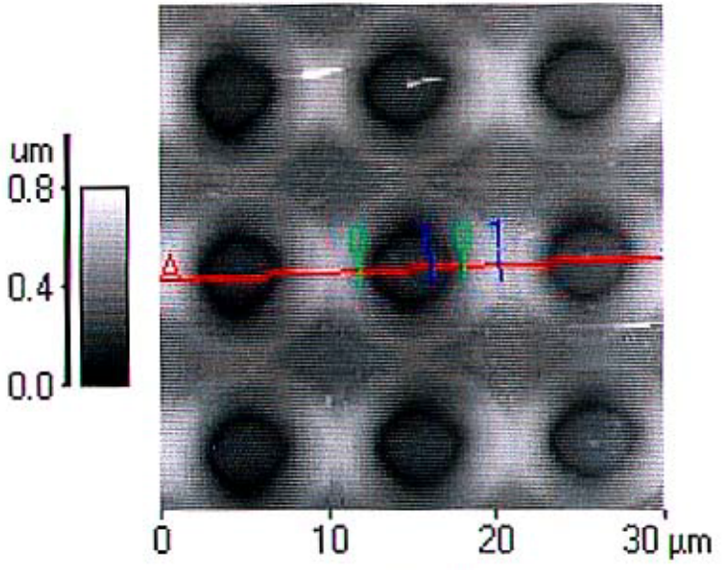
Array of holes of 6 µm diameter.

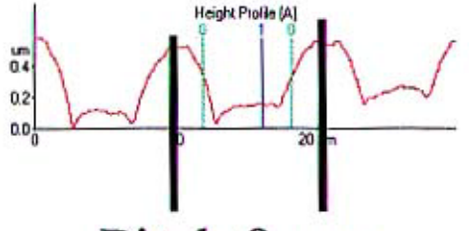
SEM



Pitch 12 µm Pitch 9 µm

AFM



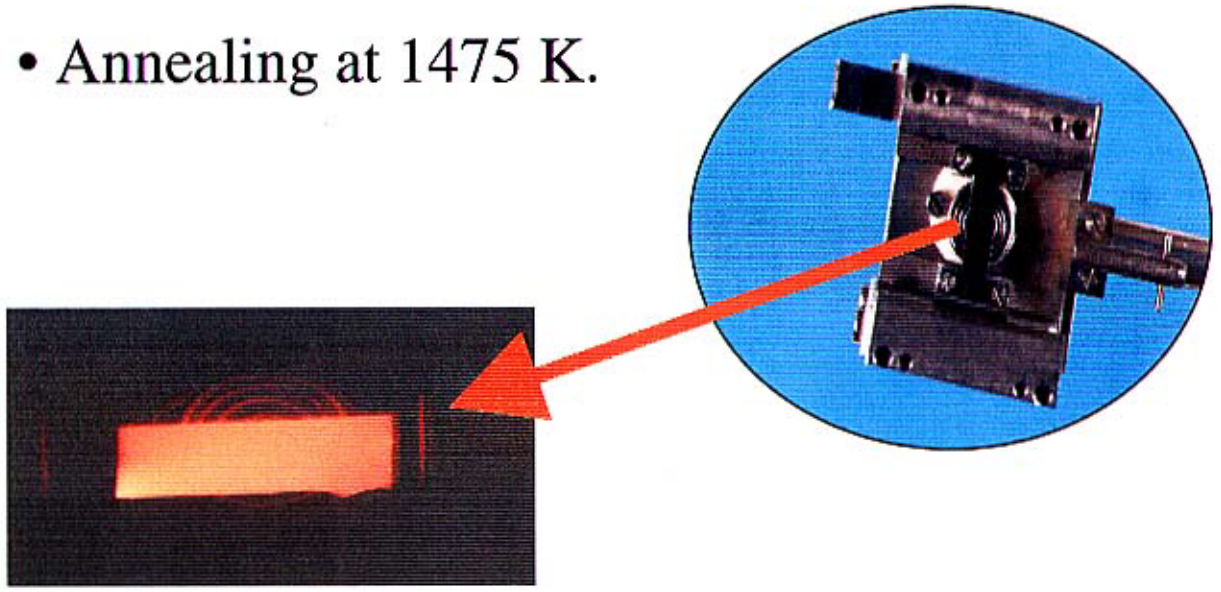


Pitch 9 µm

Process

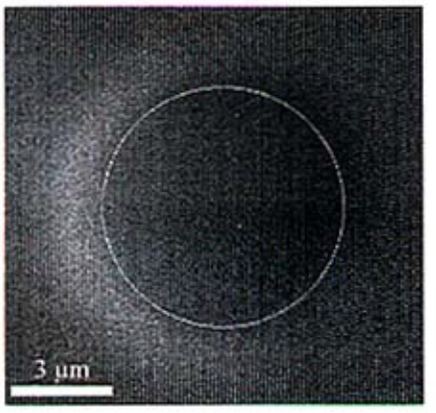
Preparation for thermal treatment

- We cut the sample to the size of 5×15 mm^2.
- Cleaned by a chemical solution : Selectipur.
- Thermal treatment : Heated by a Direct Current under UHV (10^{-10} Torr) in one STM/MBE chamber.
  - Degazing and cleaning.
  - Annealing at 1475 K.



Results

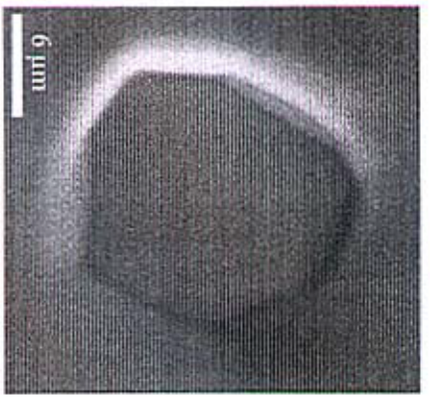
Annealing of a single cavity



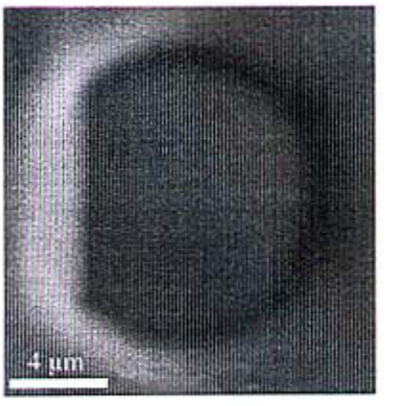
SEM pictures

6 µm cavity
as-elaborated.

Annealing at 1475 K during 30 min.



Current Effect



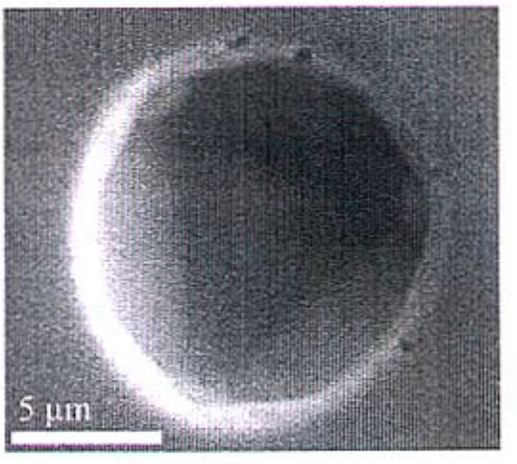
$\vec{J}$: $[1\bar{1}0]$

Anisotropic shape

$\vec{J}$: $[11\bar{2}]$

Without Current

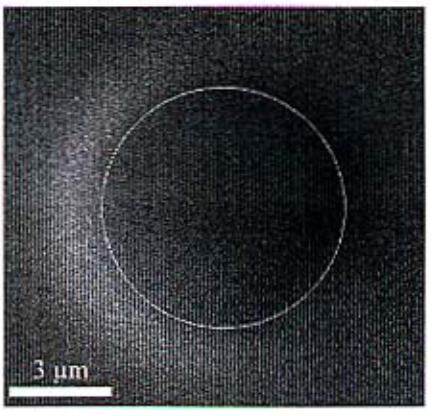
The shape of hole
is symmetric.



$[11\bar{2}]$

Results

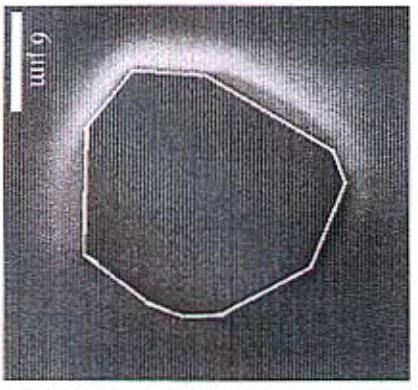
Annealing of a single cavity



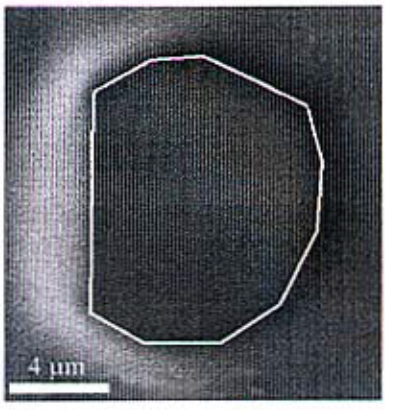
SEM pictures

6 µm cavity
as-elaborated.

Annealing at 1475 K during 30min.



Current Effect



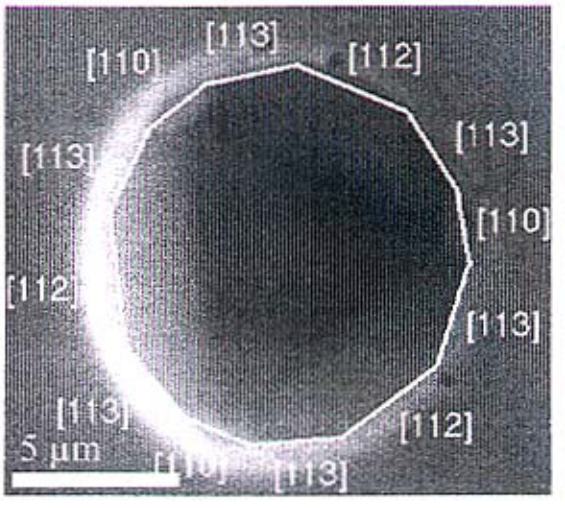
$\vec{J} : [1\bar{1}0]$

Anisotropic shape

$\vec{J} : [11\bar{2}]$

Without Current

12 facets are present.

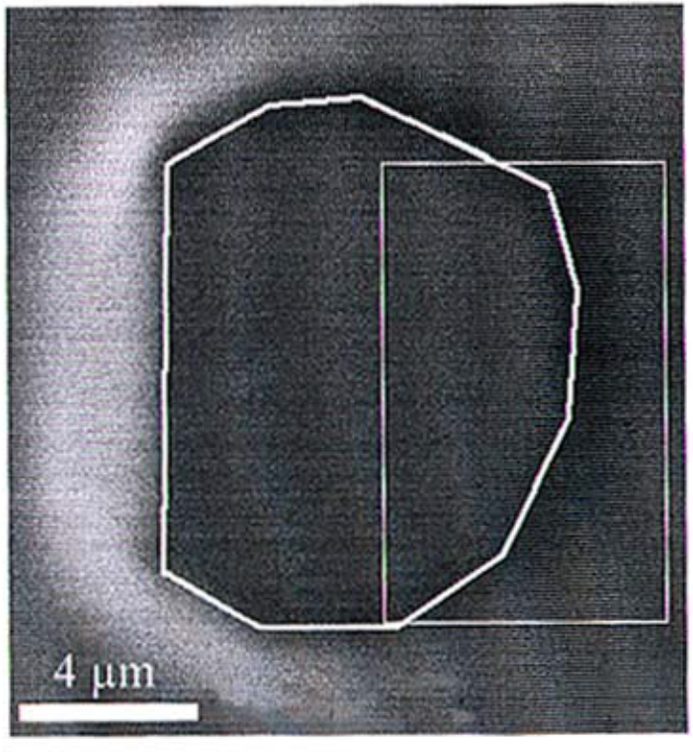


$[11\bar{2}]$

Results

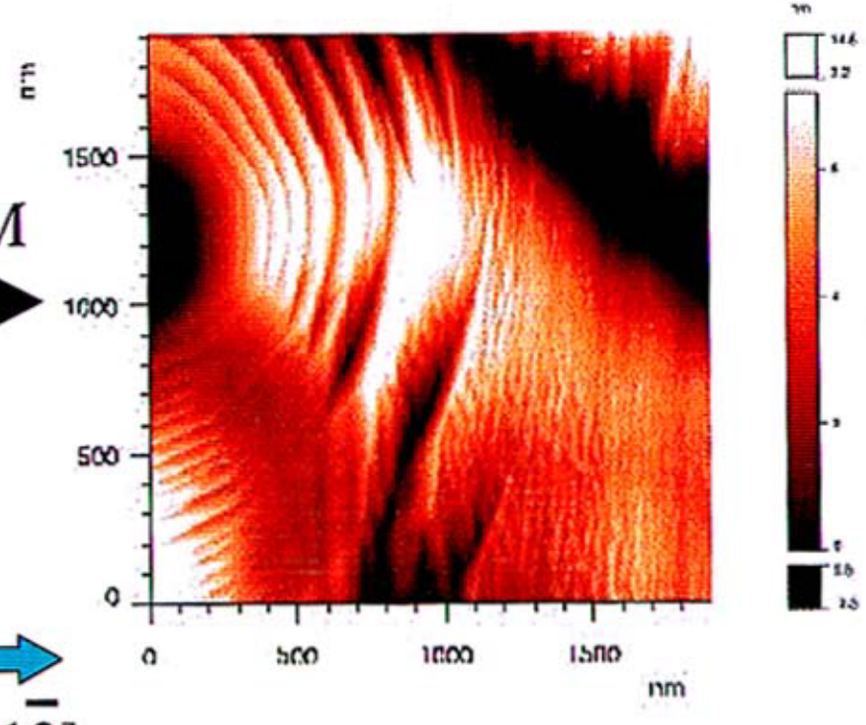
Step bunching in the hole

SEM picture
A hole annealed $\vec{J}$: [1$\bar{1}$2].



ZOOM

STM picture
A part of hole after a flash
at 1475 K.



$\vec{J}$: [1$\bar{1}$2]

Essential

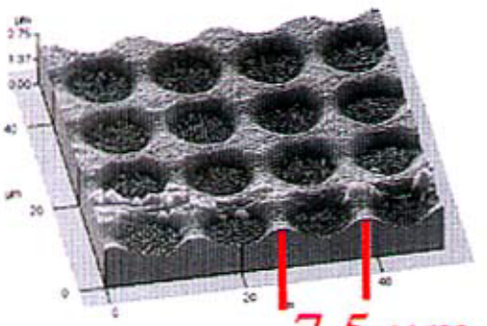
Effect of the annealing

For a single cavity heated at 1475 K during 30 min :

- Hole diameter increases ($\times 4$).
- No current $\rightarrow$ Faceting and isotropy.
- With current $\rightarrow$ Step bunching and anisotropy

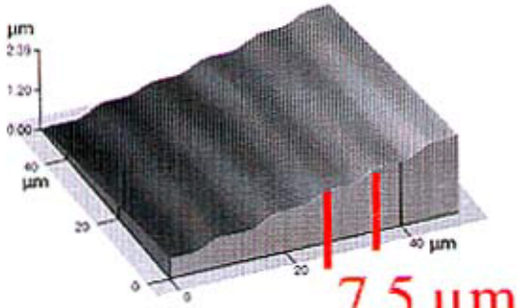
Results

Interaction within an array of cavities



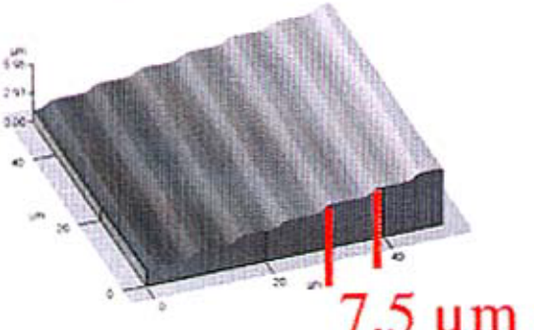
Array of cavities :
diameter 6 µm.
pitch 7.5 µm.

Formation of step bunch



Annealing at 1475 K by direct current.

No more evolution



With the time the bunches are stable and step edges are more and more straight.

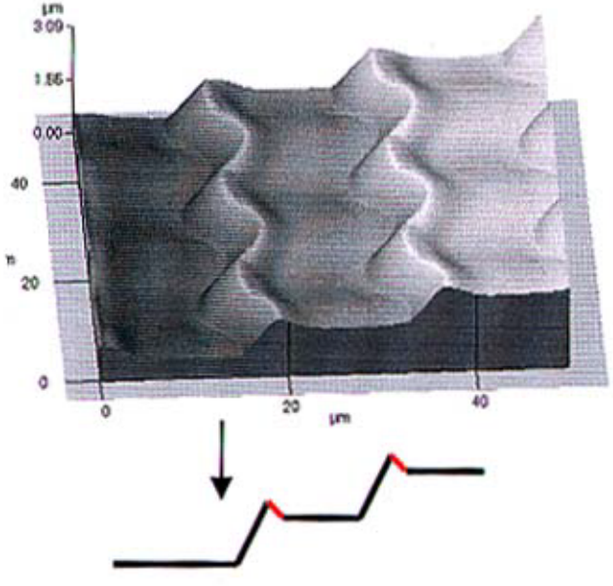
Results

Influence of polar angle Φ_0

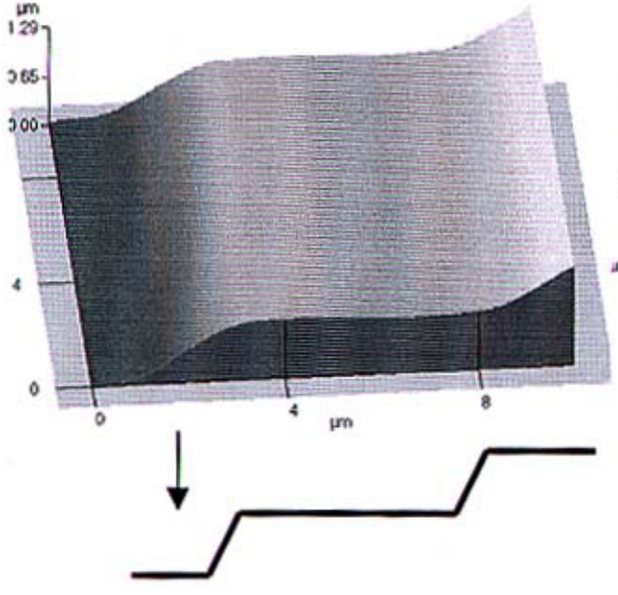
In function of the **depth of hole** (**h**) and the **pitch** (**p**), there are 3 cases depending on the aspect ratio :

$$h/p = \tan \Phi$$

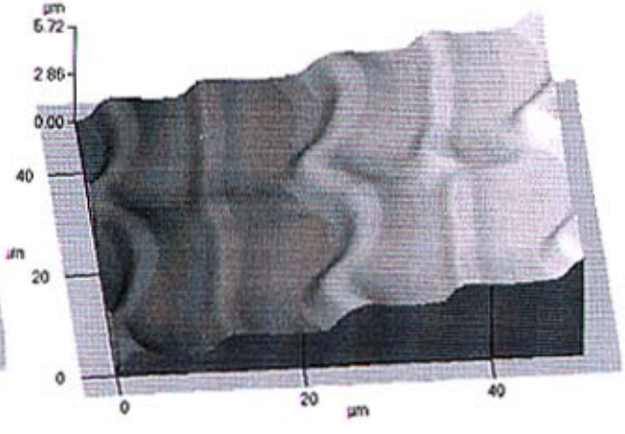
$\Phi < \Phi_0$
Anti bunch formation



$\Phi = \Phi_0$
Flat macro-terrace



P > Natural step bunching

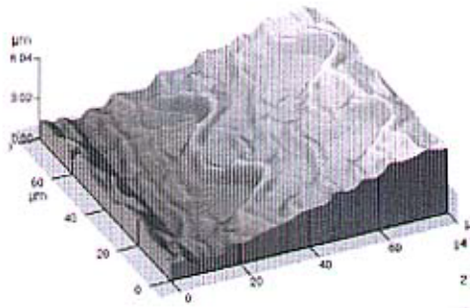


Formation of additional natural step bunches

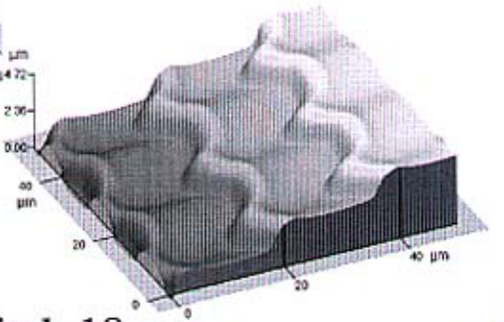
Results

Evolution of the interaction between cavities

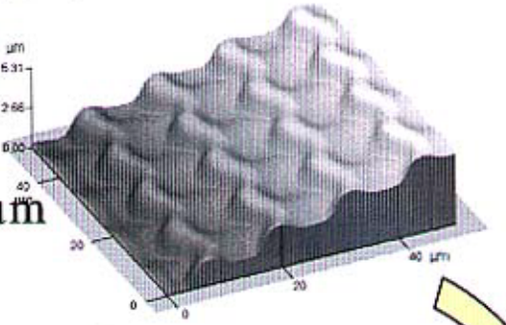
Using the different pitch present in the same sample, we propose a 'stopped dynamic'.



Pitch 36 µm

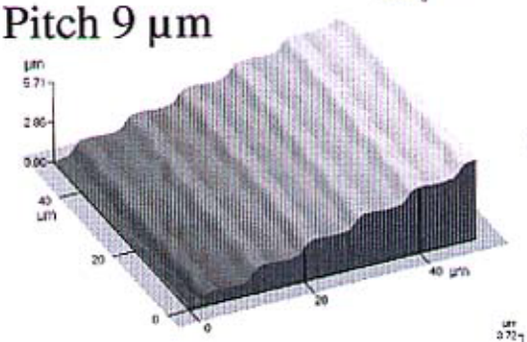


Pitch 18 µm



Pitch 12 µm

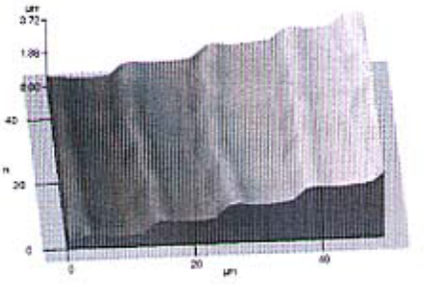
Annealing at 1475 K



Pitch 9 µm

After one hour more

Pitch 7.5 µm



PITCH ≈ TIME

Essential

Array of holes

With an array of holes, a regular step bunching is produced.

The parameters of this array are given by the pitch of the initial array of holes.

Results

What about current effect ?

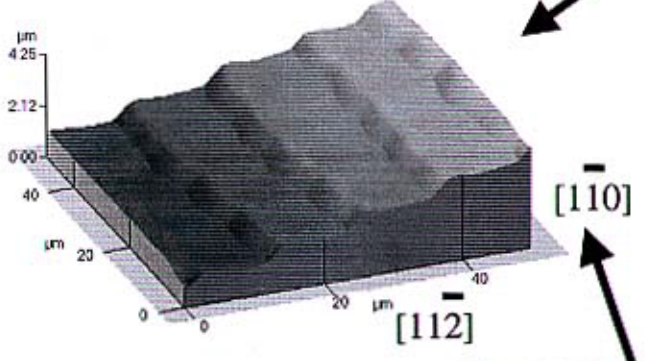
Initial surface 8 µm diameter — Annealing at 1475 K

$\vec{J}$ [11$\bar{2}$]

Same final state
(small pitch 16 µm)

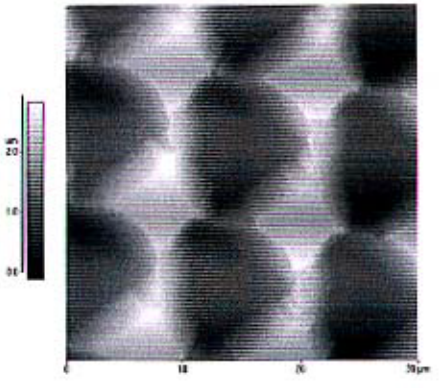
$\vec{J}$ [1$\bar{1}$0]

$\vec{J} = 0$

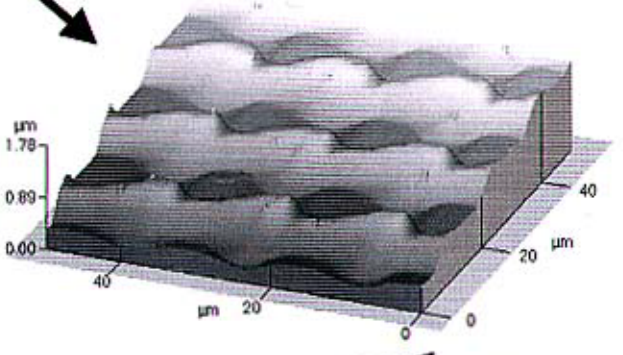


[1$\bar{1}$0]

[11$\bar{2}$]

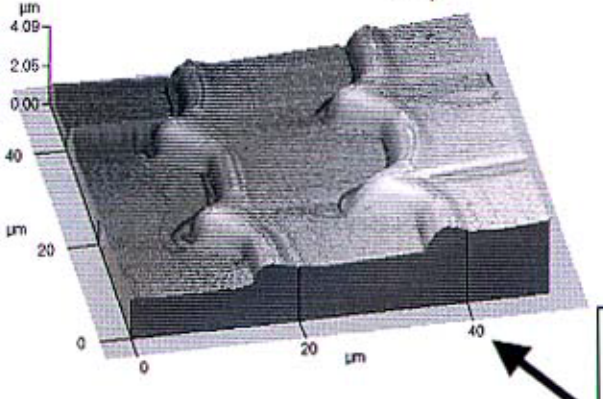


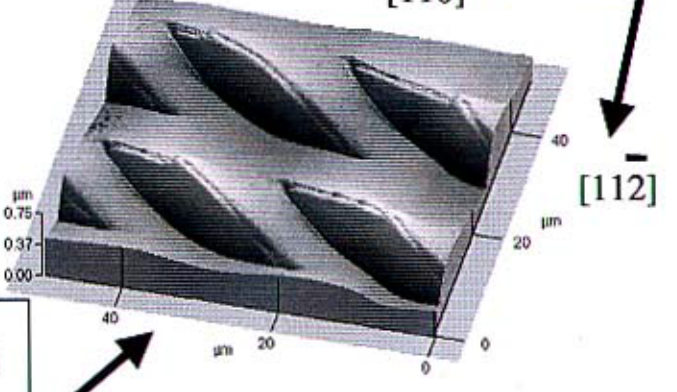
No step bunching



[1$\bar{1}$0]

[11$\bar{2}$]



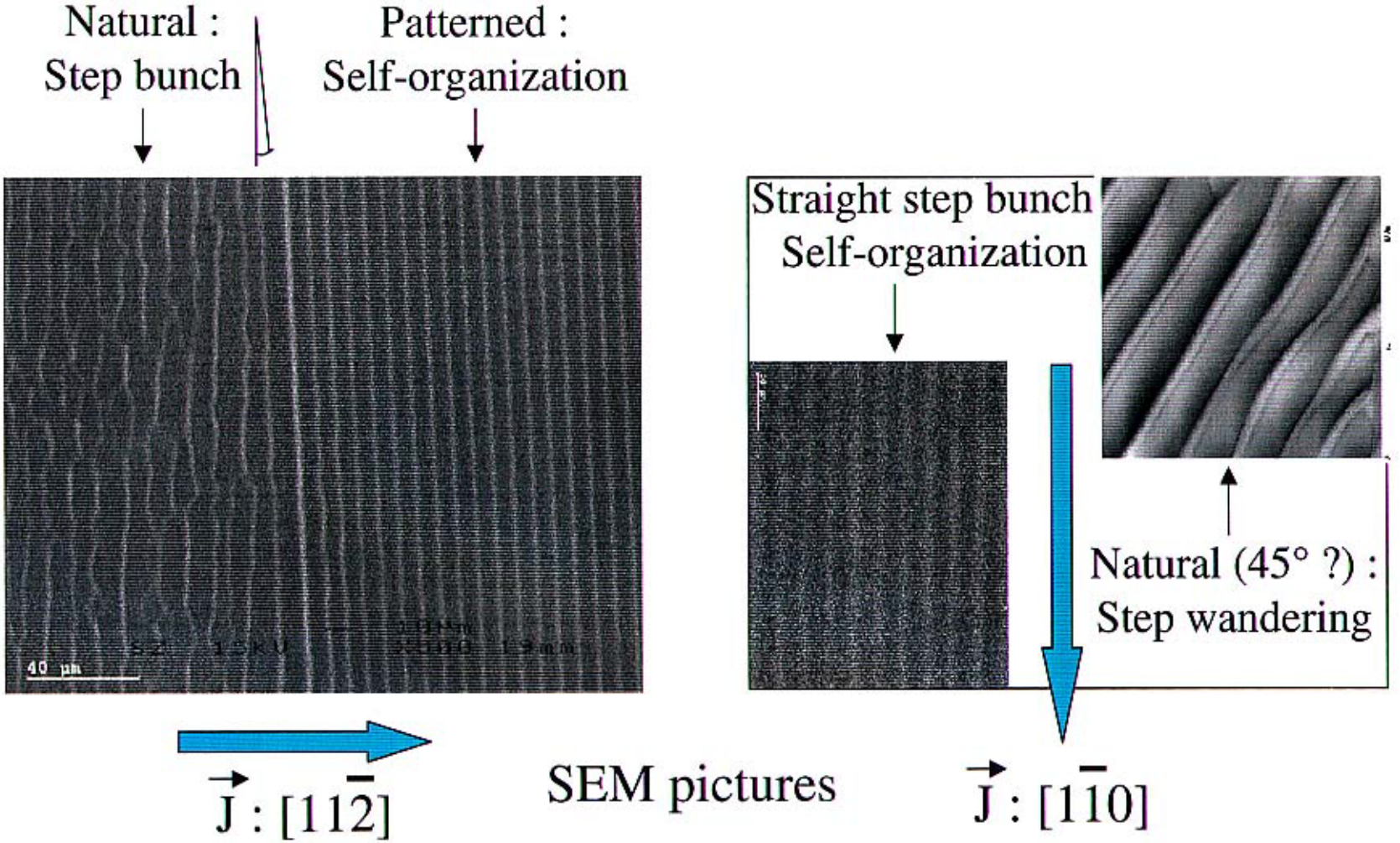


Different interaction
(larger pitch 24 µm)

Results

Orientation of the macro-bunch

The orientation is principally given by the direction of the array.



Conclusion

→ We succeeded in the fabrication of patterned substrate with specific geometric features :

Regular array of straight step bunches.

→ Can be varied :

- Periodicity (width of terraces).
- Height of the bunch.
- Design (straight or cross hatch patterns).

→ Mechanism is due to the step bunching.

Electromigration plays a role but does not disturb the final equilibrium shape.