Observation of Cu crystallographic grains by using x-ray microbeam

X線微小ﾋﾞｰﾑを用いた微細Cu配線の結晶粒解析

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Introduction

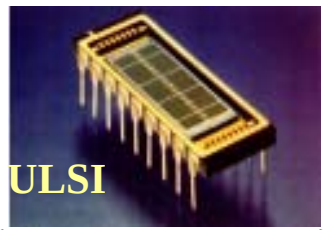
Roadmap of semiconductor device technology (ITRS2003)

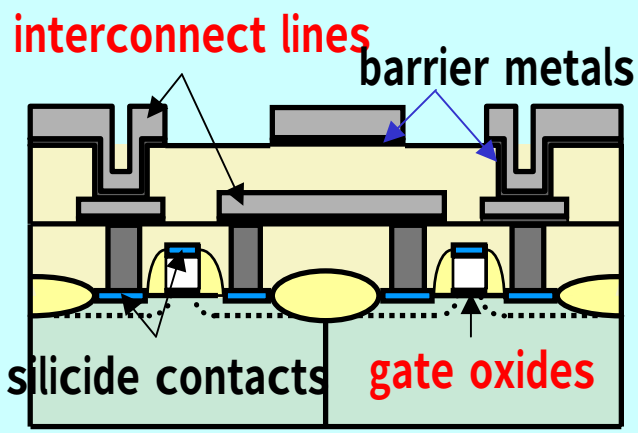
Year of production	'04	'06	'08	'18
DRAM half pitch (nm)	90	70	57	18
MPU gate length (nm)	37	28	22	7
Chip frequency (GHz)	4.17	6.78	11.0	53.2

New materials and techniques are introduced into fabrication processes

Cu interconnect technology

(Damascene process)

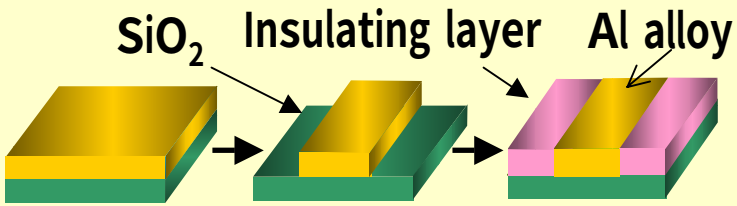




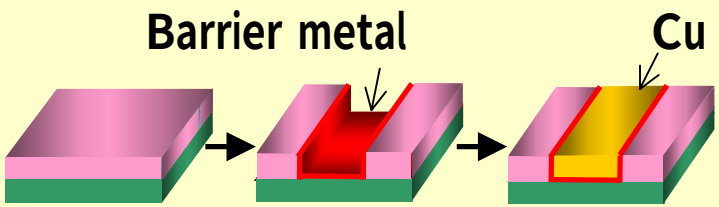
Cross section of CMOS

Fabrication process

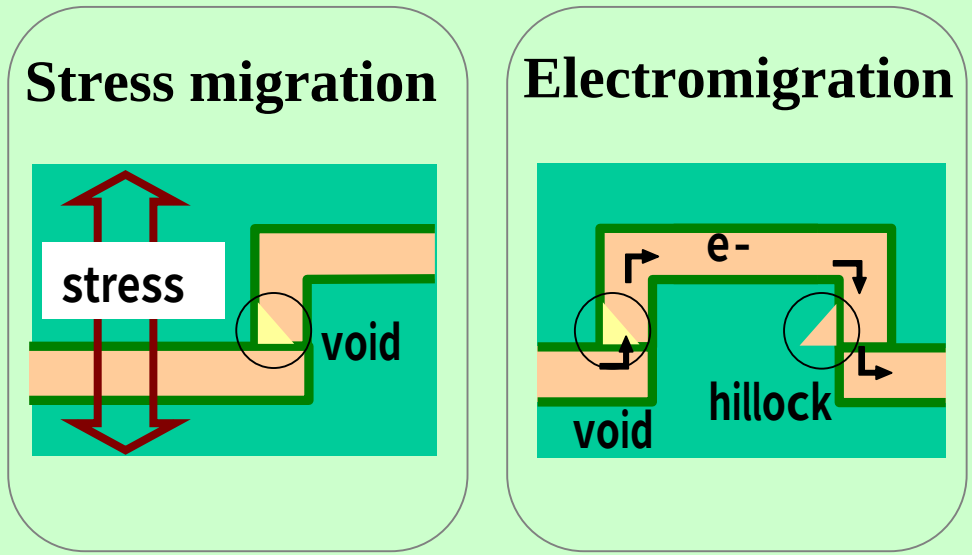
How crystallographic grains affect failure in Cu interconnects?



Etching process



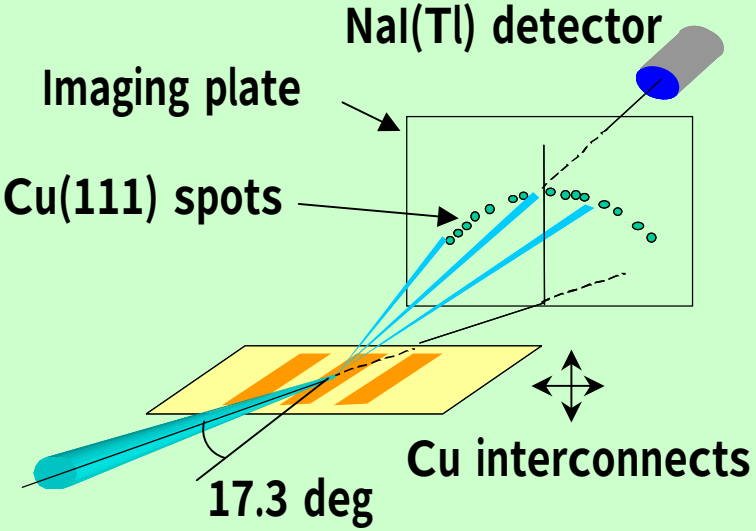
Electroplating process
(Damascene process)



Failure in Cu interconnects

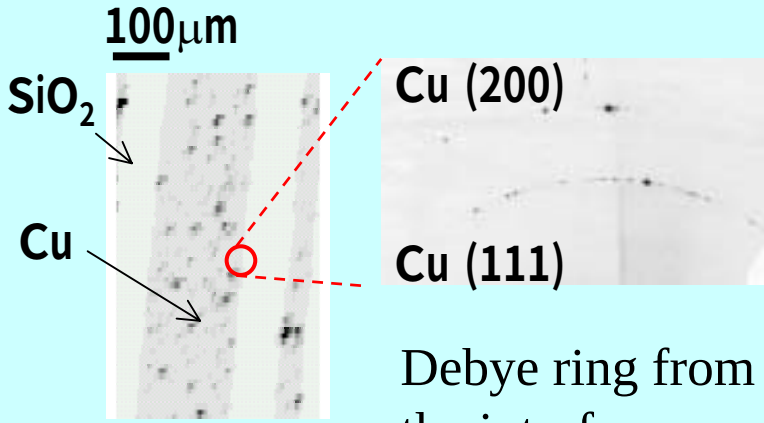
Study the status of crystallographic grains microscopically.
Observe crystallographic grains under current load.

Microdiffraction imaging and microanalysis



X-ray microprobe
(10keV, 1μm sq., 10^{10}photons/s)

Scanning x-ray microscope



Debye ring from the interface

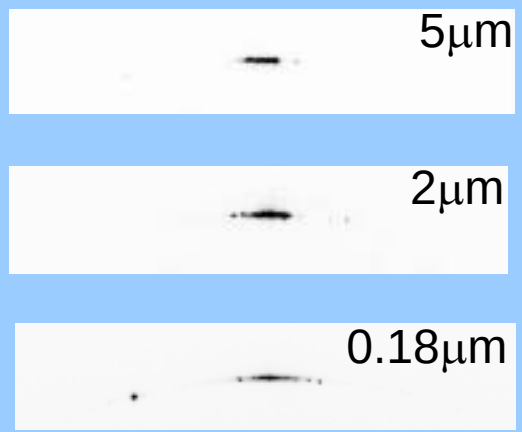
Cu(111) diffraction imaging

Side-wall growth

We have observed (111) orientation of grains parallel to the side wall.

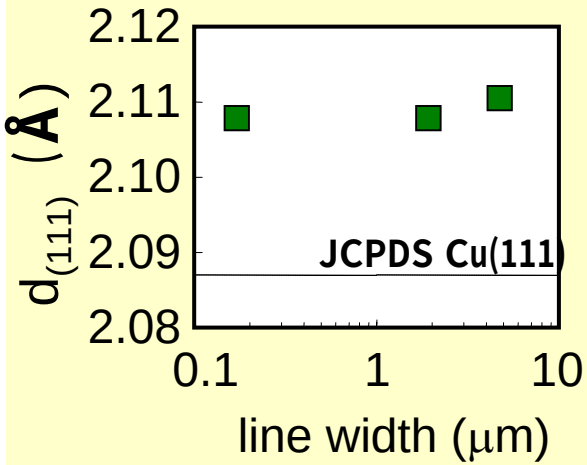
M.Hasegawa and Y.Hirai :J. Appl. Phys. 90 (2001) 2792.

Observation of strain in submicron interconnects

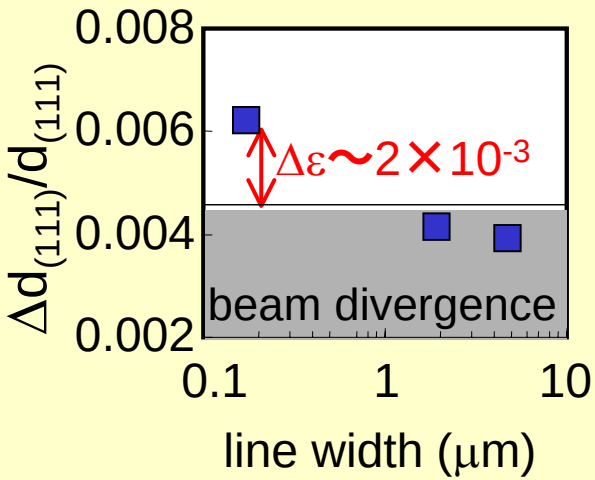


- Line width:
  5μm, 2μm, 0.18μm
- Width : 0.2μm
- Top layer: 7μm

Cu(111) diffraction spots



Average of d value

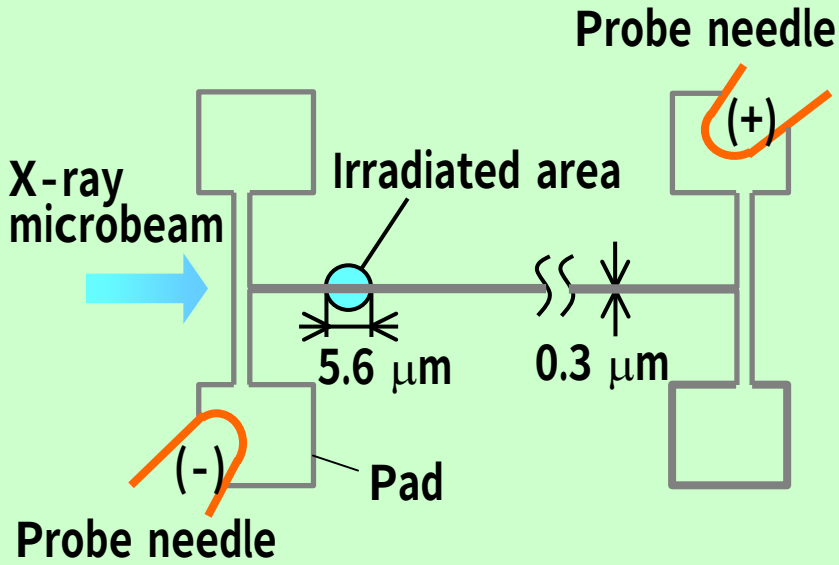


Divergence of d value

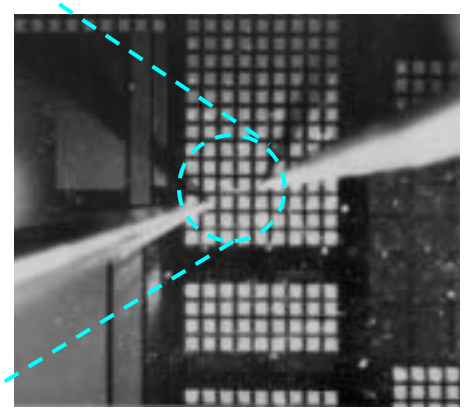
Orientation of grains diverges due to side-wall growth.
This effect and elastic anisotropy bring about large strain.

$\Delta\varepsilon \sim 2\times10^{-3}$ → **0.5MPa**

Set up for *in-situ* experiments



Test structure of *in-situ* experiments

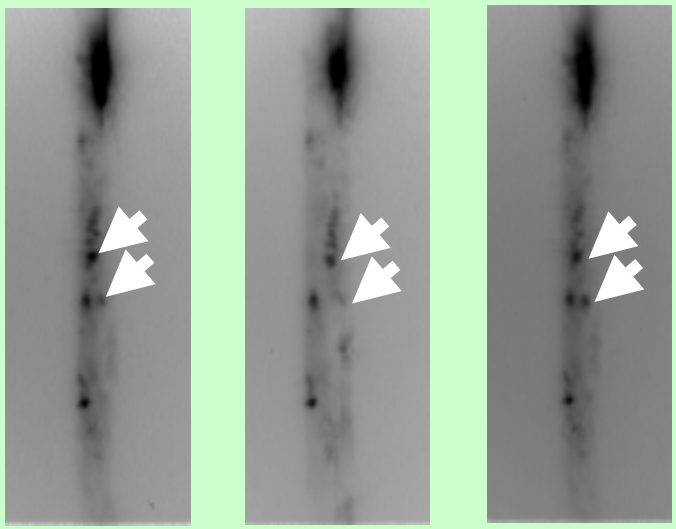


Optical microscope image

X-ray microbeam : 11keV, 2μm x 2μm
Detector : CCD camera

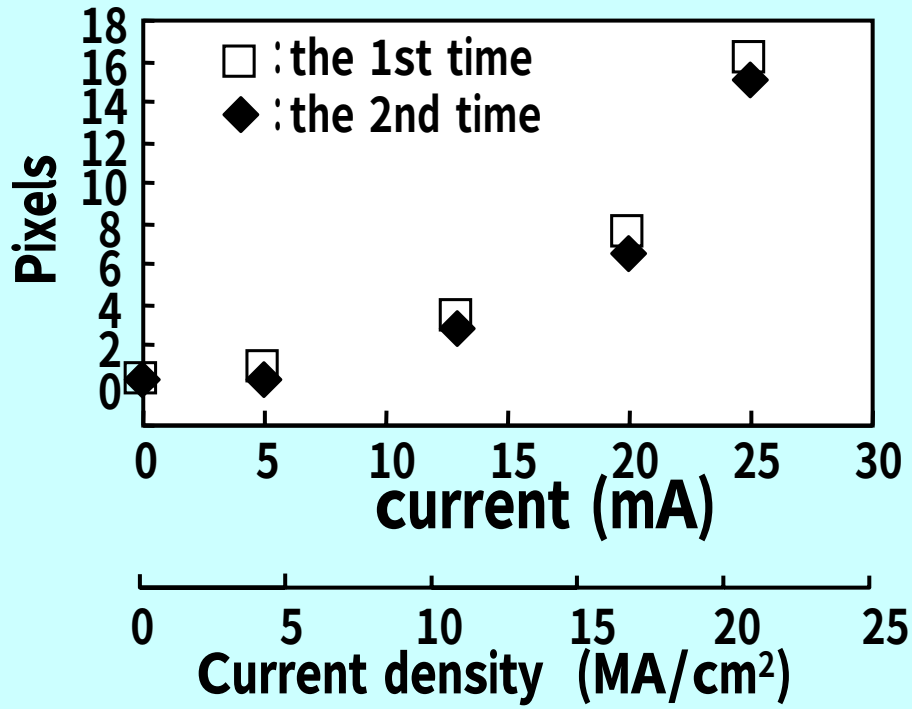
We monitored changes of diffracted spots from Cu grains of 0.3-mm-wide line by using CCD camera during a current load.

In-situ observation of Cu crystallographic grains



I= 0mA I= 25mA (21MA/cm^2) Off

Microdiffraction patterns



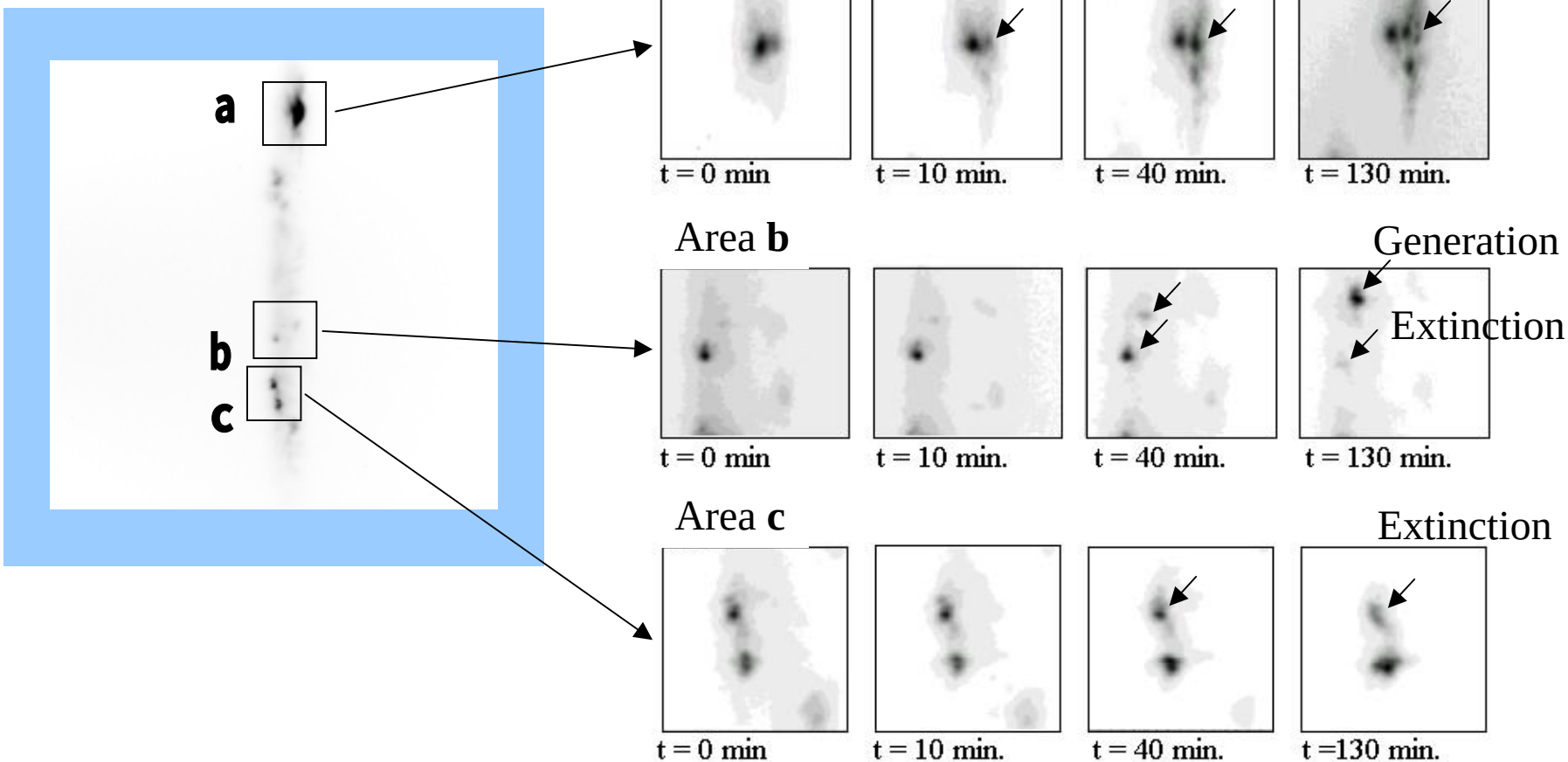
Shift of diffraction spot

Spot positions change by passing an electric current through interconnects, and their movements are reversible.

In-situ observation of time-resolved microdiffraction

Spots from (111) plane
before current loading

I=25mA (21MA/cm^2)



Results

(1) We have observed (111) orientation of grains parallel to the side wall. This effect suggests the generation of large strain. Strain in 0.18-μm-wide interconnect is estimated as $\Delta\varepsilon \sim 2\times10^{-3}$. → 0.5MPa

(2) We have monitored changes of diffracted x-ray spots from Cu grains during a current load. Movement of about 15pixels in amount corresponds to an rotational angle of 0.04deg.