Application of the ATOMKI-ECRIS for materials research and prospects of the medical utilization

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Collaborators:

- *National Institute of Radiological Sciences (NIRS), Chiba, Japan*
- *Bio-Nano Electronics Research centre, Toyo University, Kawagoe, Japan*
- *Division of Electrical Engineering, Osaka University, Osaka, Japan*
- *Tateyama Machine Co., Ltd., Toyama, Japan*

Outline

Introduction

1. New fullerene-based materials to be produced in ECR discharge

2. Bone cell growth on titanium coated with fullerene.

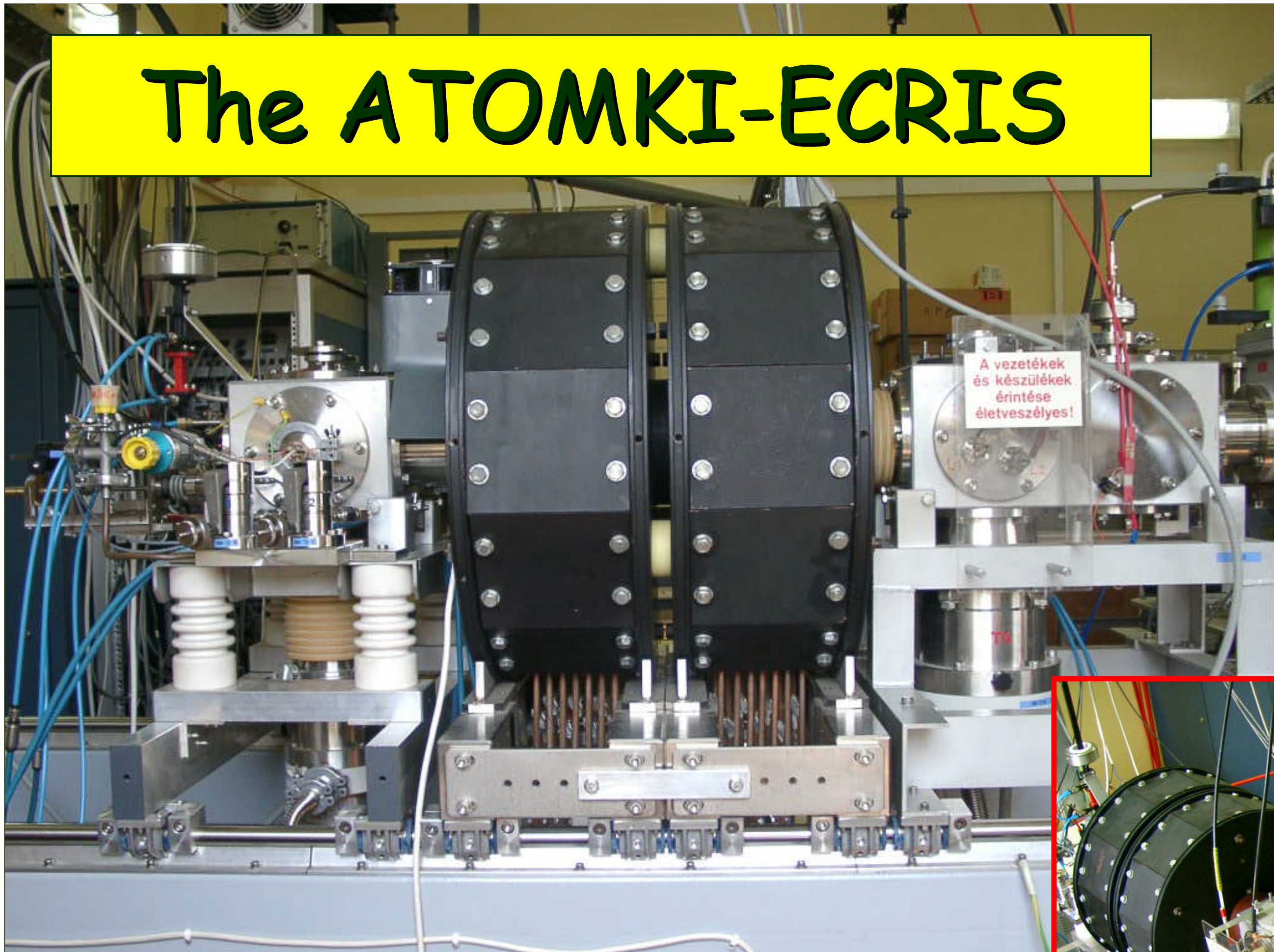
3. Optical changes in thin films by HCI irradiation

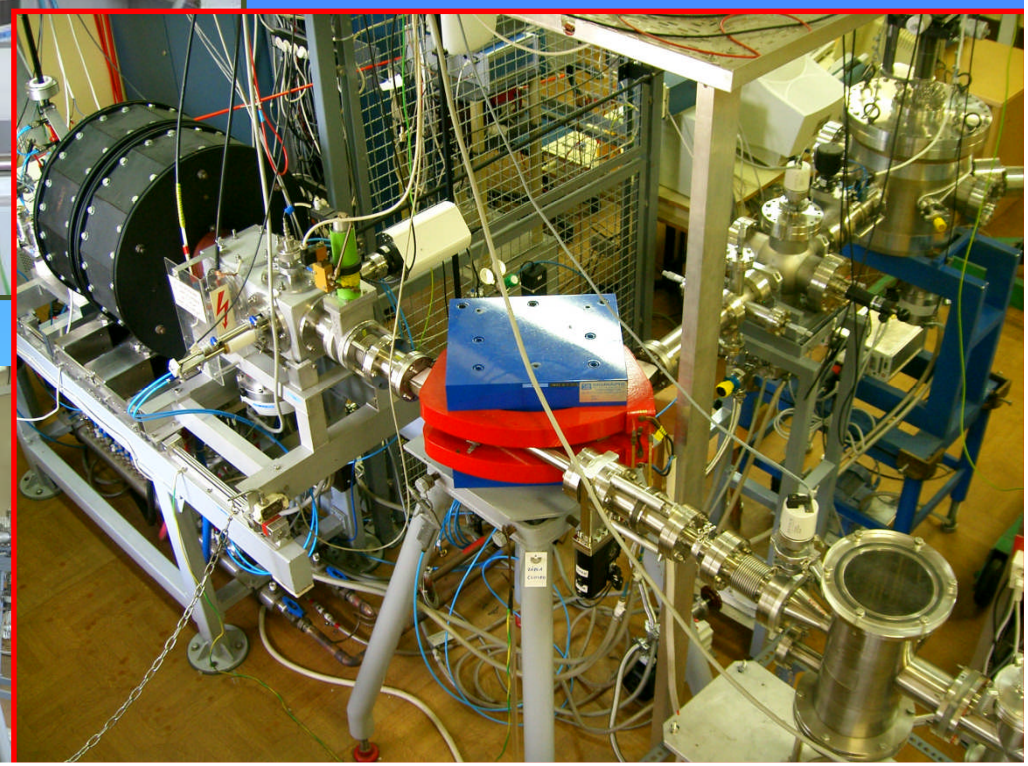
4. Guiding of HCI through nano- and micro-capillaries

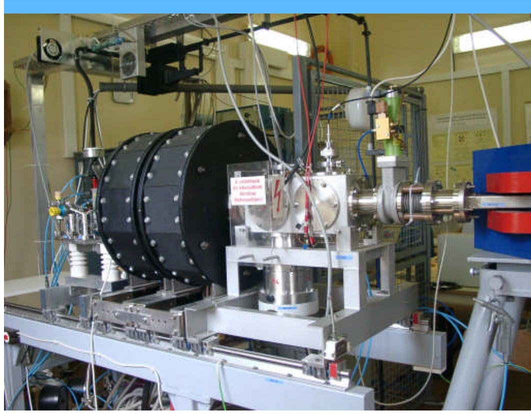
Comparison, summary

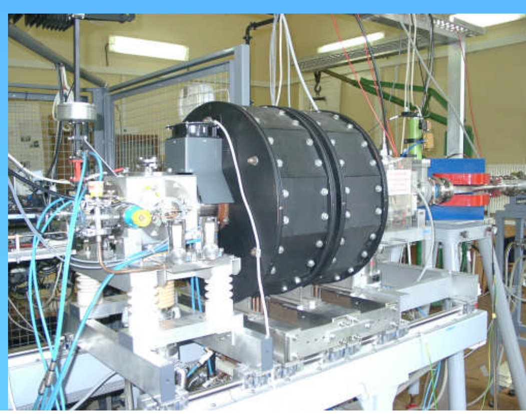
The ATOMKI-ECRIS

- 14.3 GHz/1 kW
- Axial field:1.2/0.4/1.0 T
- Radial field: 0.9 T
- Chamber: ϕ58x200
- Extraction: 0.2-30 KV

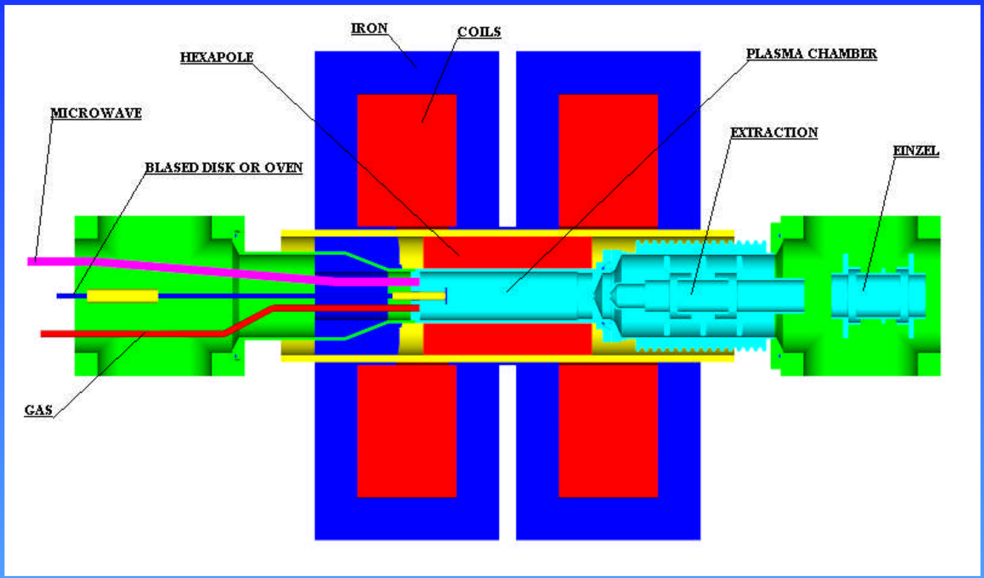


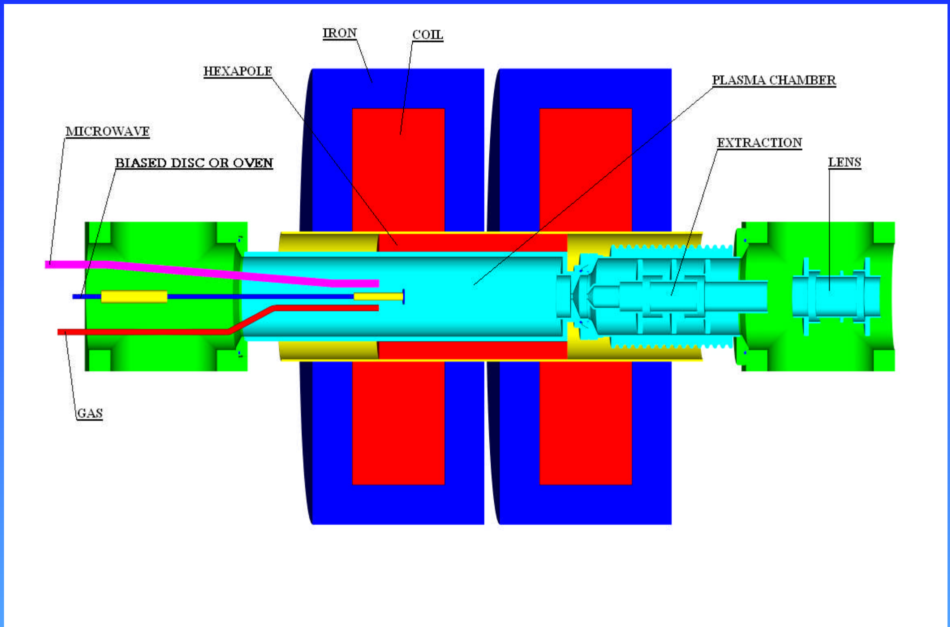






Two versions of the ECRIS





ATOMKI-ECRIS-A

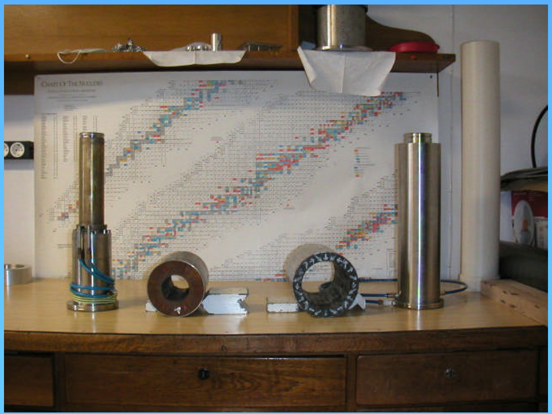
ATOMKI-ECRIS-B

Klystron, 14 GHz, 1000 W

Magnets: 1.2/0.4/1.0 and 0.9 T

Plasma chamber: ϕ6x22 cm

For HCI plasmas/beams



TWTAs, 6-18 GHz, 20 W

Magnets: 0.9/0.3/0.9 and 0.7 T

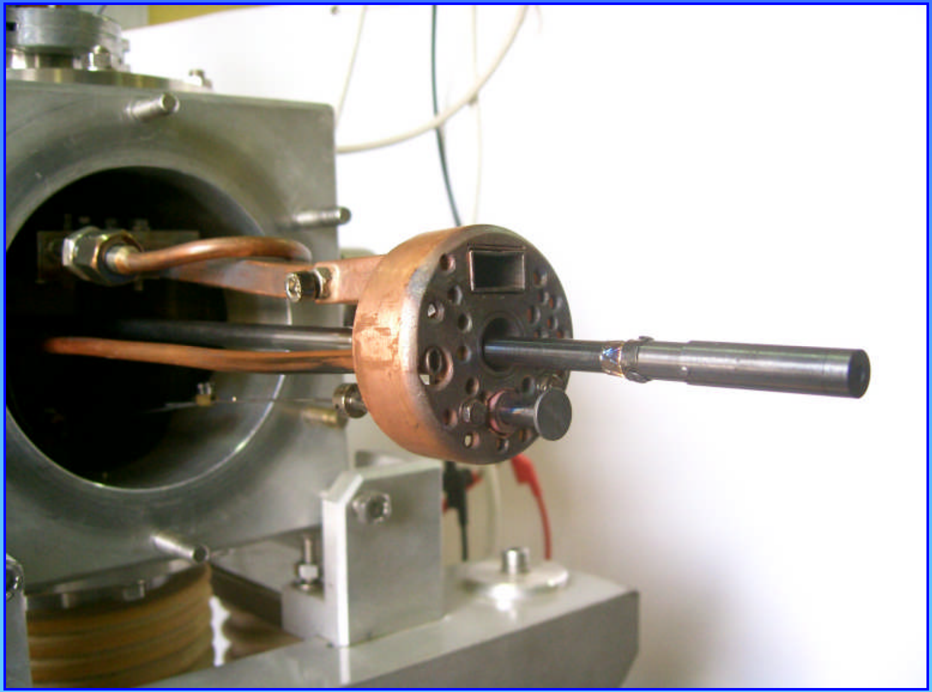
Plasma chamber: ϕ10x40 cm!

For LCI, large-size plasmas

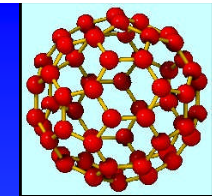
1. Fullerene-based new materials (C_{60}+X) to be produced in ECR-discharge

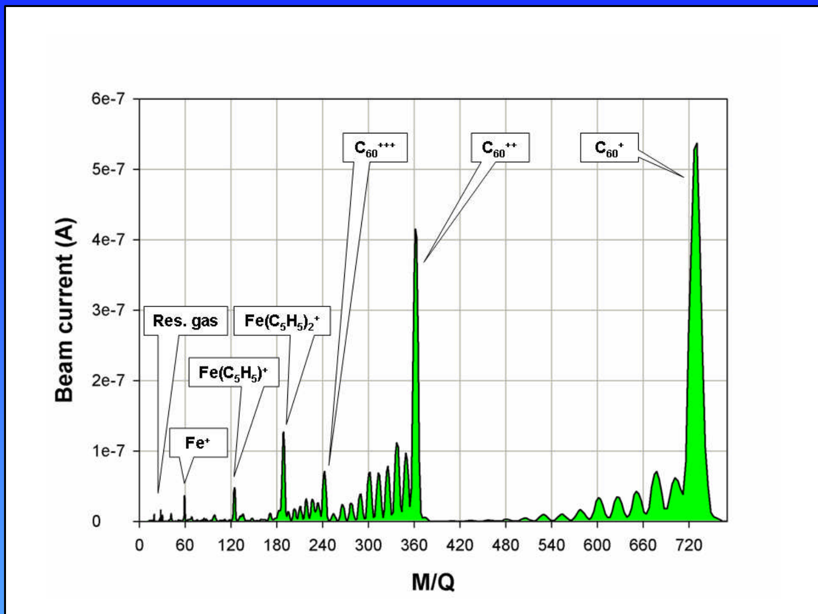
Since 2000 fullerene plasmas and beams have been produced at the ATOMKI ECRIS

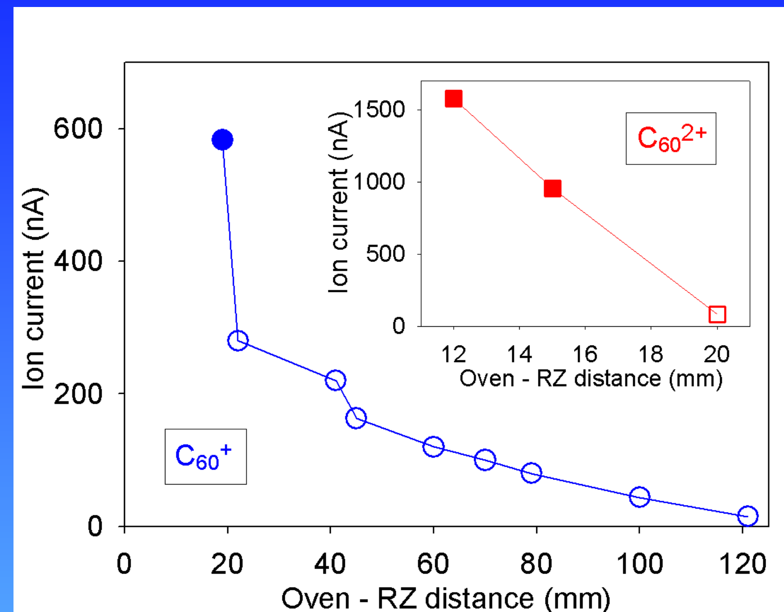
- C_{60}: just a working material (as Ne, Ar, Fe), no „C_{60} research"
- Production of C_{60} ion beam (intensity, charge)
- Fullerene derivatives (destroying-adding)
- Mixture plasmas (C_{60}+X)
- New materials (by C_{60}+X) to detect in beam
- New materials to produce in macroscopic quantity
- Applications (surface coating, etc.)

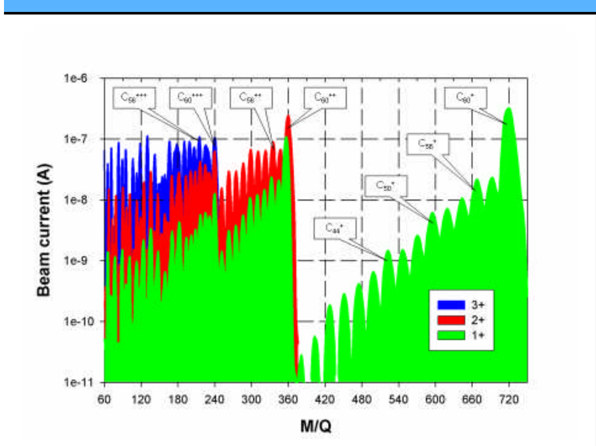


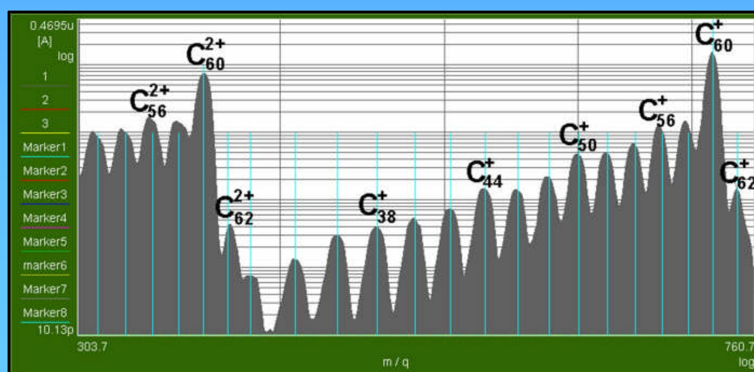
Basic C60 experiments



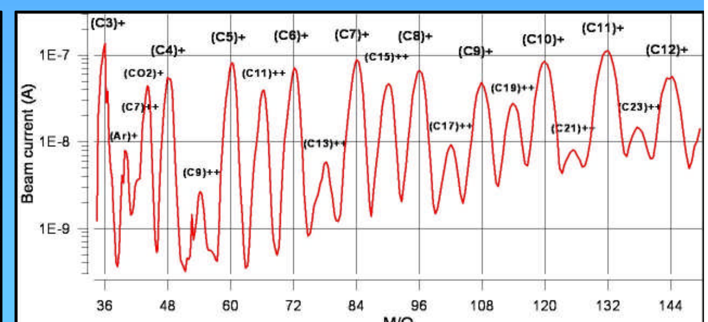




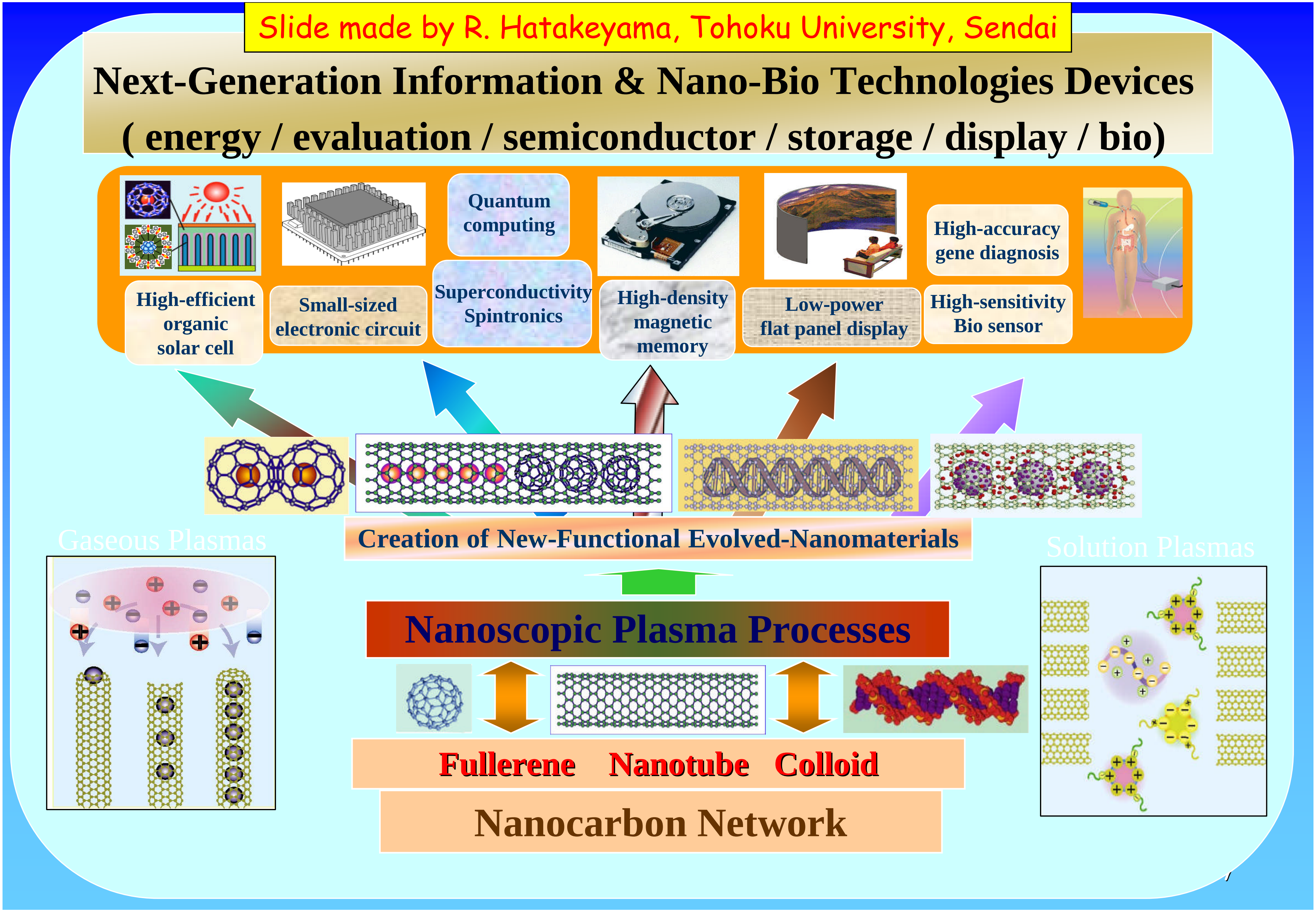




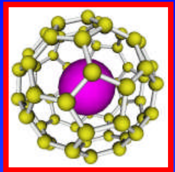
Typical fullerene derivative spectrum. The plasma was tuned for C_{62}^{+}. The well-known shape of the derivative peaks is clearly observed.



*Fullerenes can break into **clusters**: carbon chains or rings with atom numbers between 2 and 30 (both odd and even). Spectrum shows plasma tuned for C_{11}^{+}. Highest peaks: 3+, 7+, 11+, etc. The 4n+3 "magic" rule.*


Slide made by R. Hatakeyama, Tohoku University, Sendai
Next-Generation Information & Nano-Bio Technologies Devices
(energy / evaluation / semiconductor / storage / display / bio)
High-efficient organic solar cell
Small-sized electronic circuit
Quantum computing
Superconductivity Spintronics
High-density magnetic memory
Low-power flat panel display
High-accuracy gene diagnosis
High-sensitivity Bio sensor
Creation of New-Functional Evolved-Nanomaterials
Gaseous Plasmas
Solution Plasmas
Nanoscopic Plasma Processes
Fullerene
Nanotube
Colloid
Nanocarbon Network

Iron encapsulated in fullerene



Ha X=Fe $\rightarrow$ Fe@C_{60}

Nanotechnology

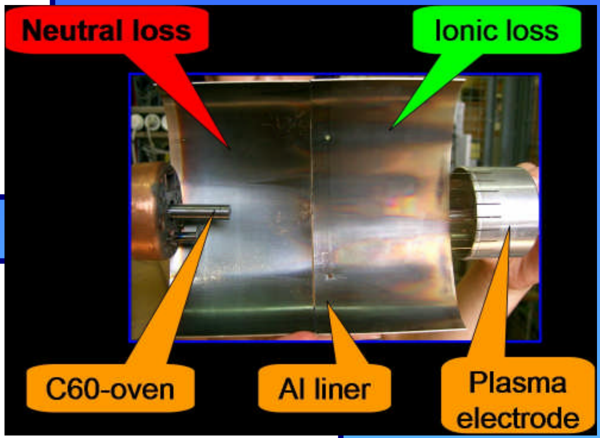
new SC materials

quantum computing

Medical tratments

ultra-contrast Magnetic Resonance Imaging (MRI) agent,

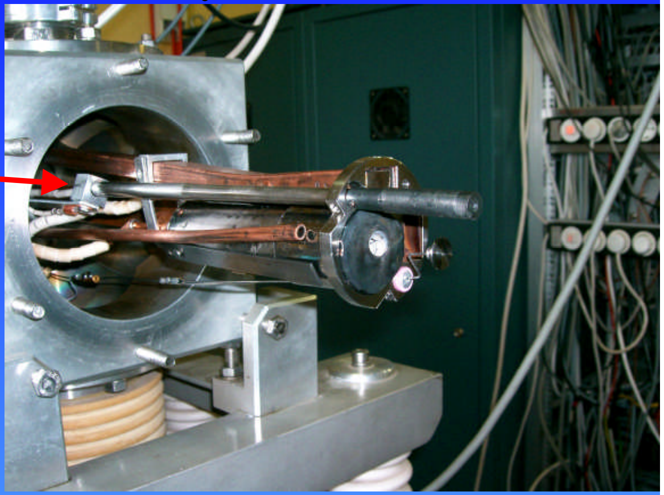
magnetic nano-particle



In ECR ion sources:

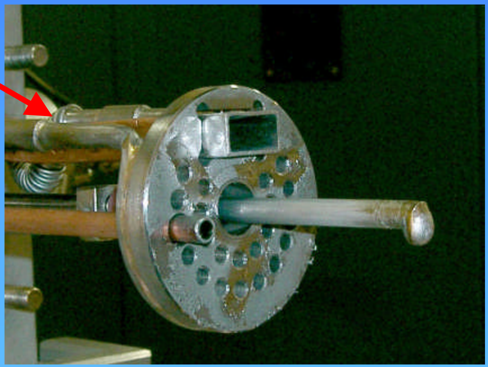
- Evaporation of C_{60} is solved (500 C)
- Production of fullerene derivatives is possible
- such as (C60)+, (C58)+, (C56)+,…, (C60)++, (C58)++, (C56)++,…,
- Calculations showed that fullerene derivatives are less stable
- Therefore we must make a two-components plasma
- 1. component: C_{60} (mass and charge to be regulated)
- 2. component: Fe: pure iron „gas", positive ions with optimal energy
- Synthesis: volume or surface?

Iron plasma in ECR ion sources (pre-experiments)

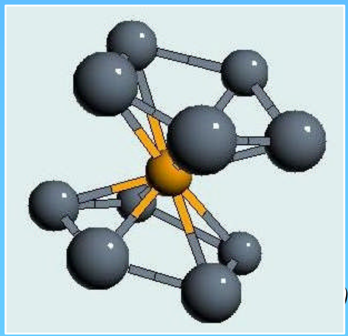


- Filament ovens: high temperature, large size, impurities

- Sputtering: high microwave power, high voltage,



- Sublimation: omly in chemical compounds, e.g. ferrocene $Fe(C_5H_5)_2$: many non-wanted C, H, C_xH_x



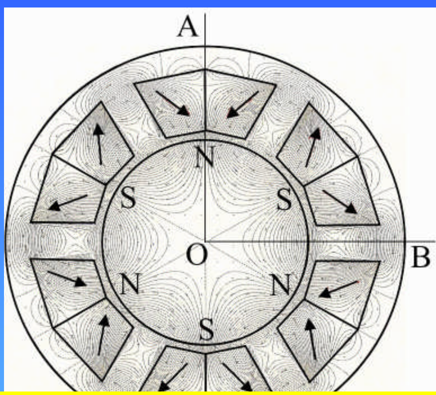
- External ion source (e.g. MEVVA): complicated to connect (?)

- Indution oven: only iron!

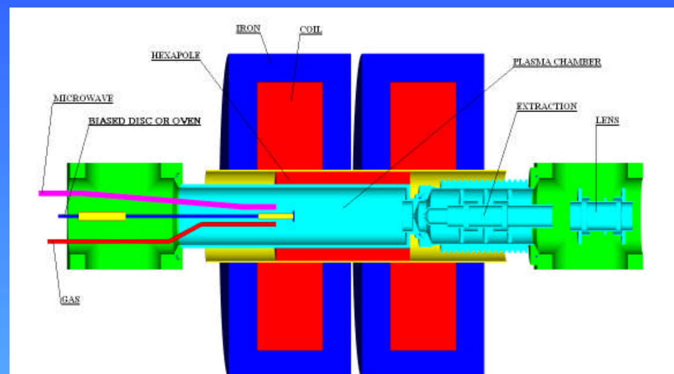
It was decided to build a new ECR ion source at Toyo University, Kawagoe, Japan.
To produce new, fullerene-based materials, mainly metal-encapsulated fullerenes.
It is called: Bio-Nano-ECRIS

Collaborators: Toyo Univ., NIRS, Osaka Univ., Tateyama Co. and ATOMKI

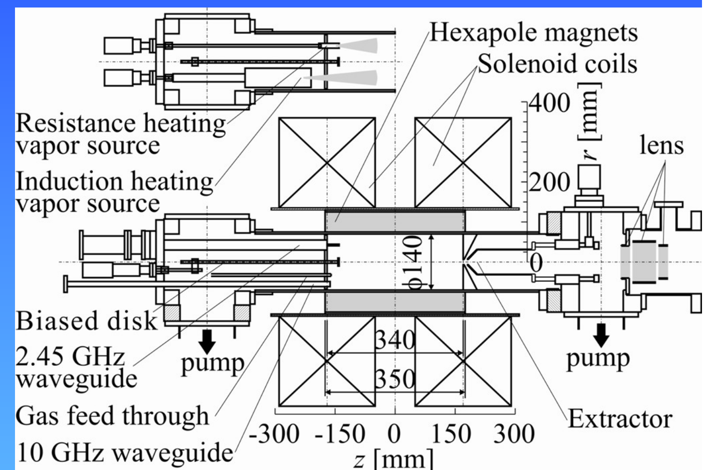
1st step: geometry and magnetic trap

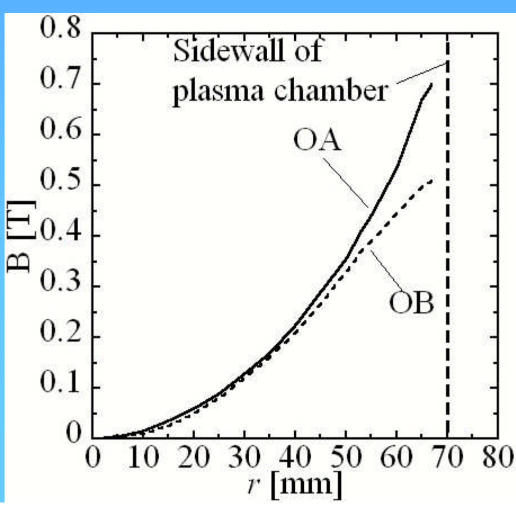


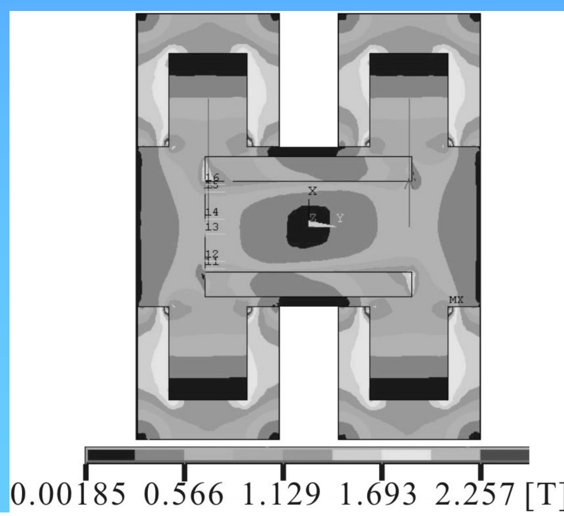
Hexapole: modified AECR-U

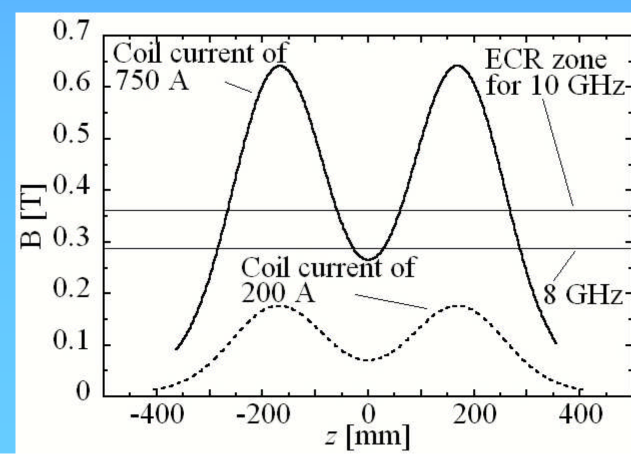


ATOMKI-ECRIS-B



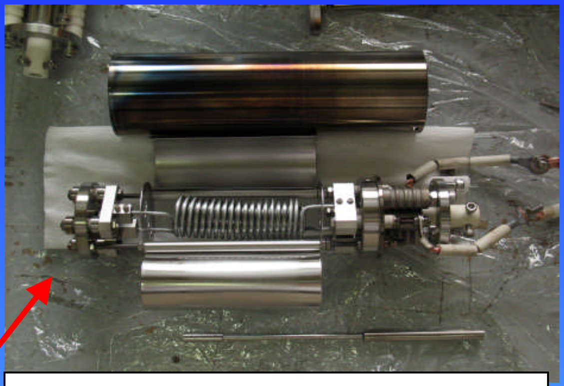




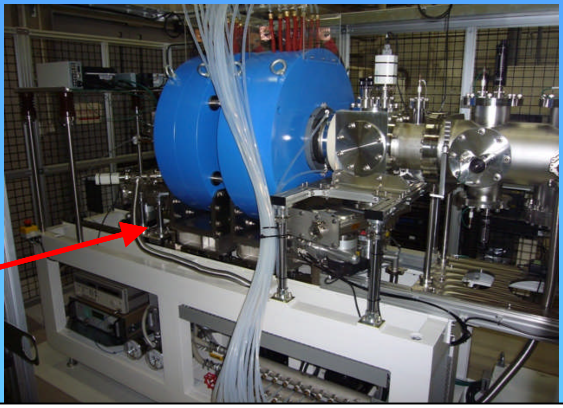


The Bio-Nano-ECRIS project at Toyo University

- Geometry: plasma chamber OD=14 cm, L=35 cm.
- Microwave: 8-10 GHz, optional 2.45 GHz 2nd frequency.
- Mirror field: 2 identical RT-coils, max. 0.64 Tesla.
- Hexapole: NdFeB, modified AECR-U design, 0.72/0.45 Tesla.
- Fullerene gas: using simple filament oven or evaporation boat.
- Iron gas: by induction oven (under development).
- Beamline: AM to transport upto 5 KV beams with M=800.
- First gas plasma: 2008 March
- Fe+C60 mixing: 2009-2010



Induction oven, under development

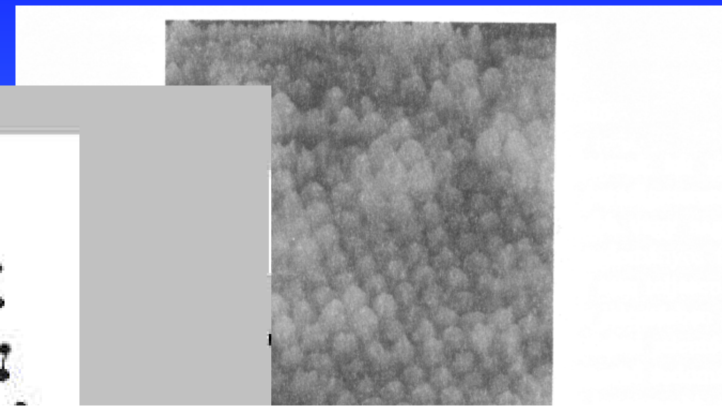


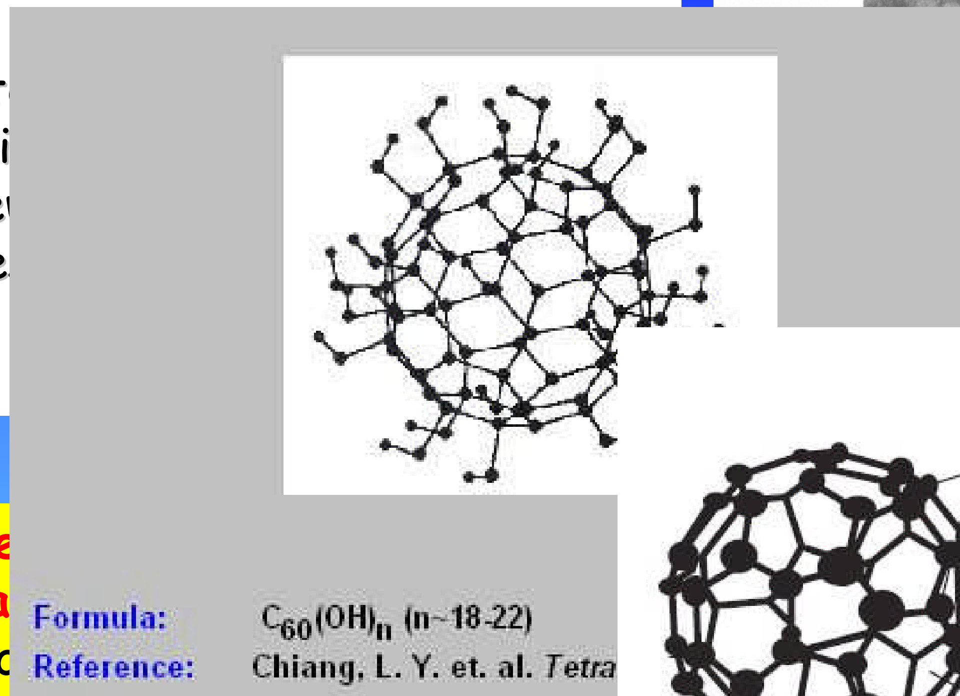
Bio-Nano-ECRIS, Toyo University, 2008

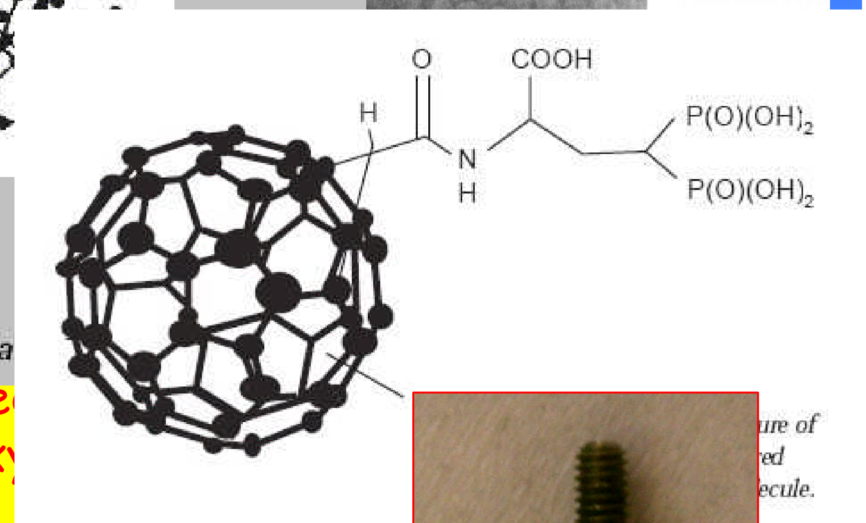
2. Bone cell growth on titanium coated with fullerene.

ATOMKI ECRIS Group and Unideb Faculty of Dentistry collaboration

- **"Osseointegration"**: bone formation on Ti implants.
- Efforts: accelerat
lifetime and mechani
- Nanotechnology: ne
- Biological usefulne
improved by (1)
(2) surface coating.

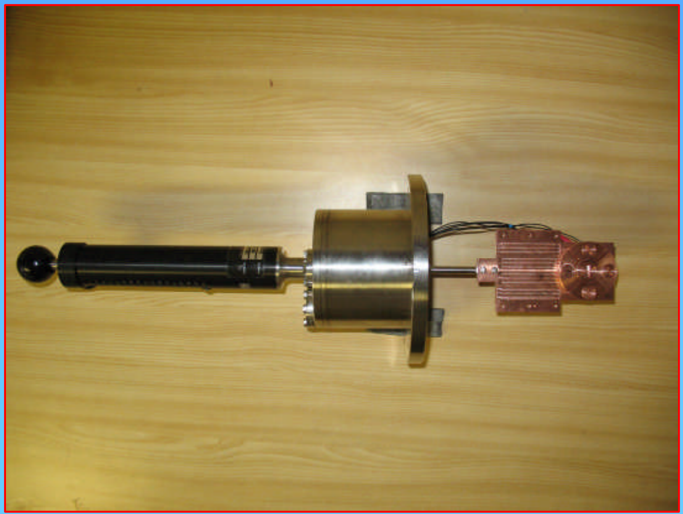


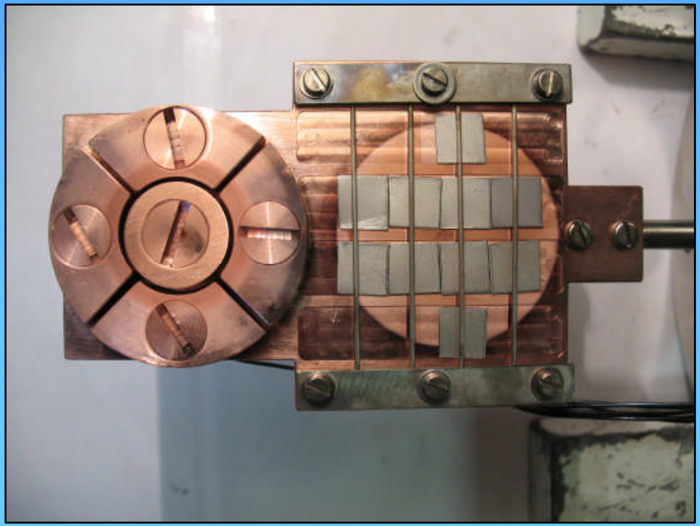


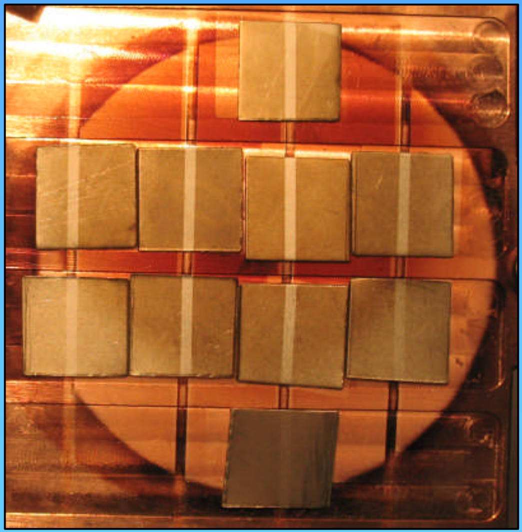


- **Our idea: fullerene**
layer between meta
- C60 ions can be sho
required velocity: balls remain intact or damage
- fullerene molecules are very reactive: hydroxy
other groups can be connected
- Such derivatised fullerenes are medically useful
- Physical part: to coat titanium surfaces by fullerenes with various velocity and thickness.
- Biological tests: growing bone cells on Ti+C60

- Task: irradiate simultaneously 10 Ti samples
- Size: 10x10x0.5 mm (d=50 mm beam is necessary)
- ATOMKI-ECRIS-B configuration
- Primary beamline, 50 cm distance from plasma
- 90% of the beam is single-charged
- 80% of the extracted beam is fullerene
- 90 deg beamline: just composition check
- U=250 V and U=500 V extraction voltages
- beam accuracy on 5 segments: less than 10% difference
- total intensity hit the samples: 300-800 enA
- C60 thickness estimated: 1 and 5 layers



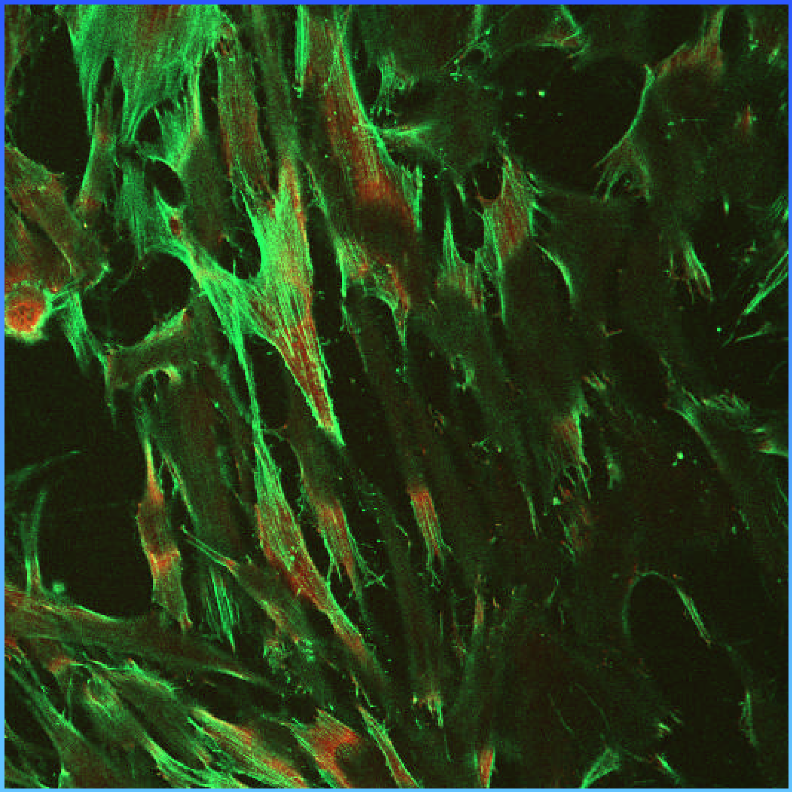




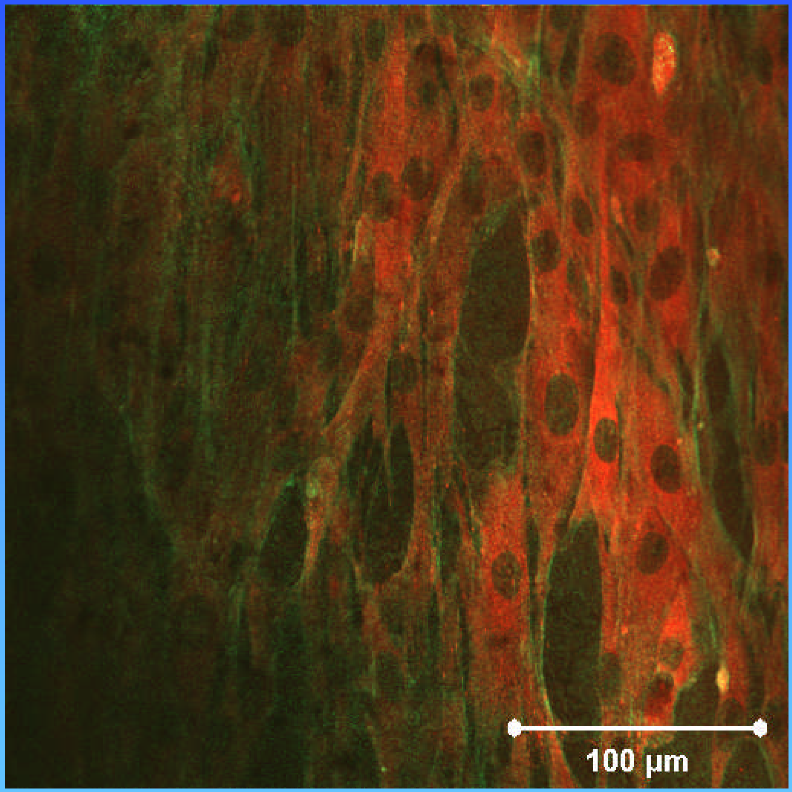
Summary of the Ti coatings by C60

Ti sample series	C_{60} fraction in beam (%)	Beam energy (eV)	Number of C_{60} molecular layers on the Ti surface	Time of irradiation (min)
1	80	500	4.3	90
2	93	500	1.2	23
3	74	250	4.9	87
4	84	250	1.1	32

•Human embryonic **bone cells** were cultured onto the Ti substrates for 48 hours (type: palatal mesenchymal pre-osteoblast, HEPM 1486, ATCC)
•Cells dual labeled with special markers (FITC-falloidin), actine and vinculine
•Confocal imaging: laser scanning microscope (LSM 510, Carl Zeiss).



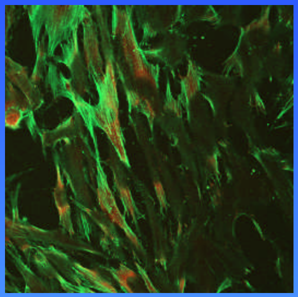
Bone cells grown on glass

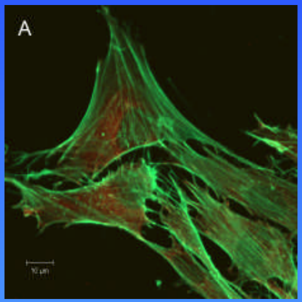


Bone cells grown on Ti+C60 (250 eV)

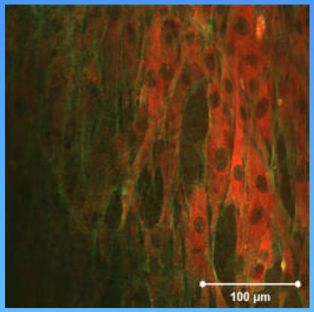
The morphology of the cells is different compared to the control substrate
The control cells on glass are quite spread showing an interconnected morphology
The cells grown on the Ti substrates are more spindle-like shape showing denser actine and vinculine structure
But there is no remarkable difference between the four Ti+C60 series, so far.

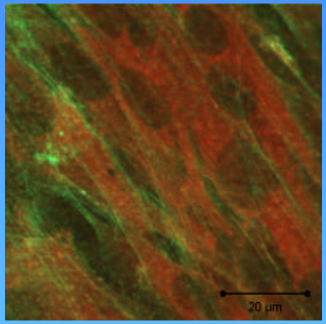
Glass:

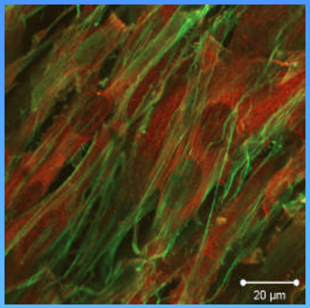


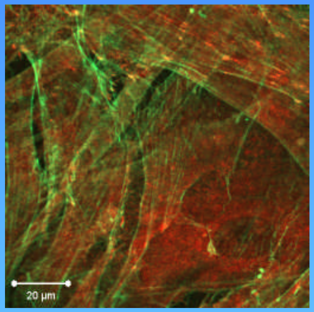


Ti+C60:





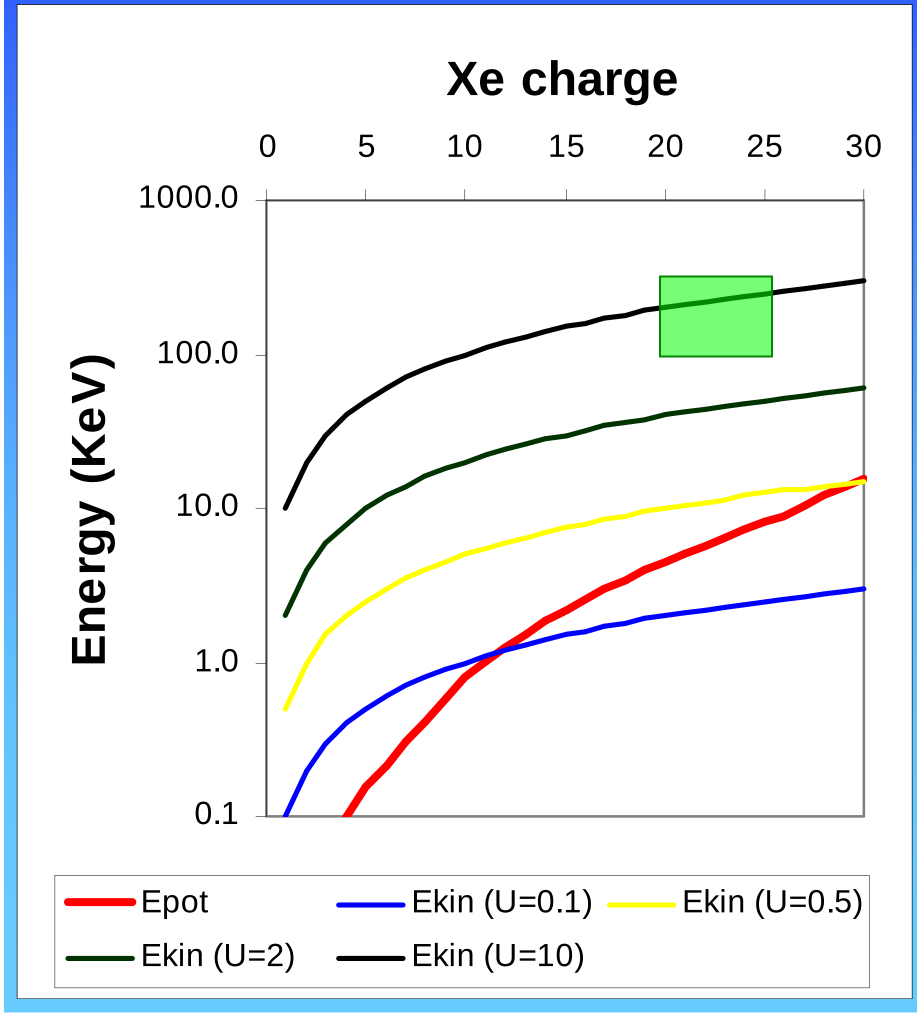


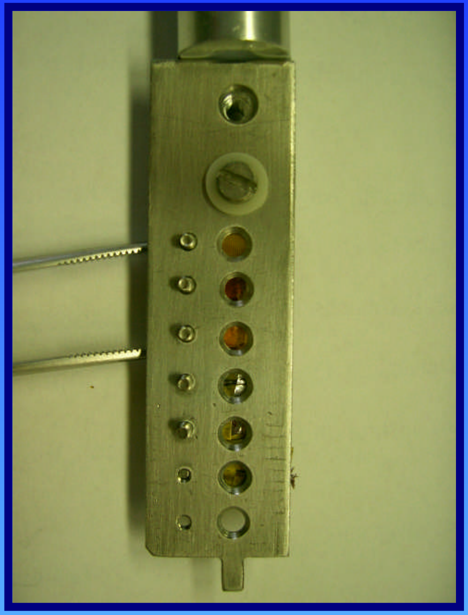


This first experiment: successful
Proved: C60 coating does not prevent bone cells grows.
High number of bone cells grew on Ti+C60 ($\sim 5*10^5$/cm3)
Further experiments: optimal beam properties
(energy, rate, density, composition)
Goal: improve physical (Ti-C60) and biological (C60-cells) properties

3. Modificaction of thin films by multiply charged ions

2004-2006: individual slow ions hitting the surface
- ❑ Amorphous Se layers, 500 nm, on mica
- ❑ Needle-like SbSJ crystals





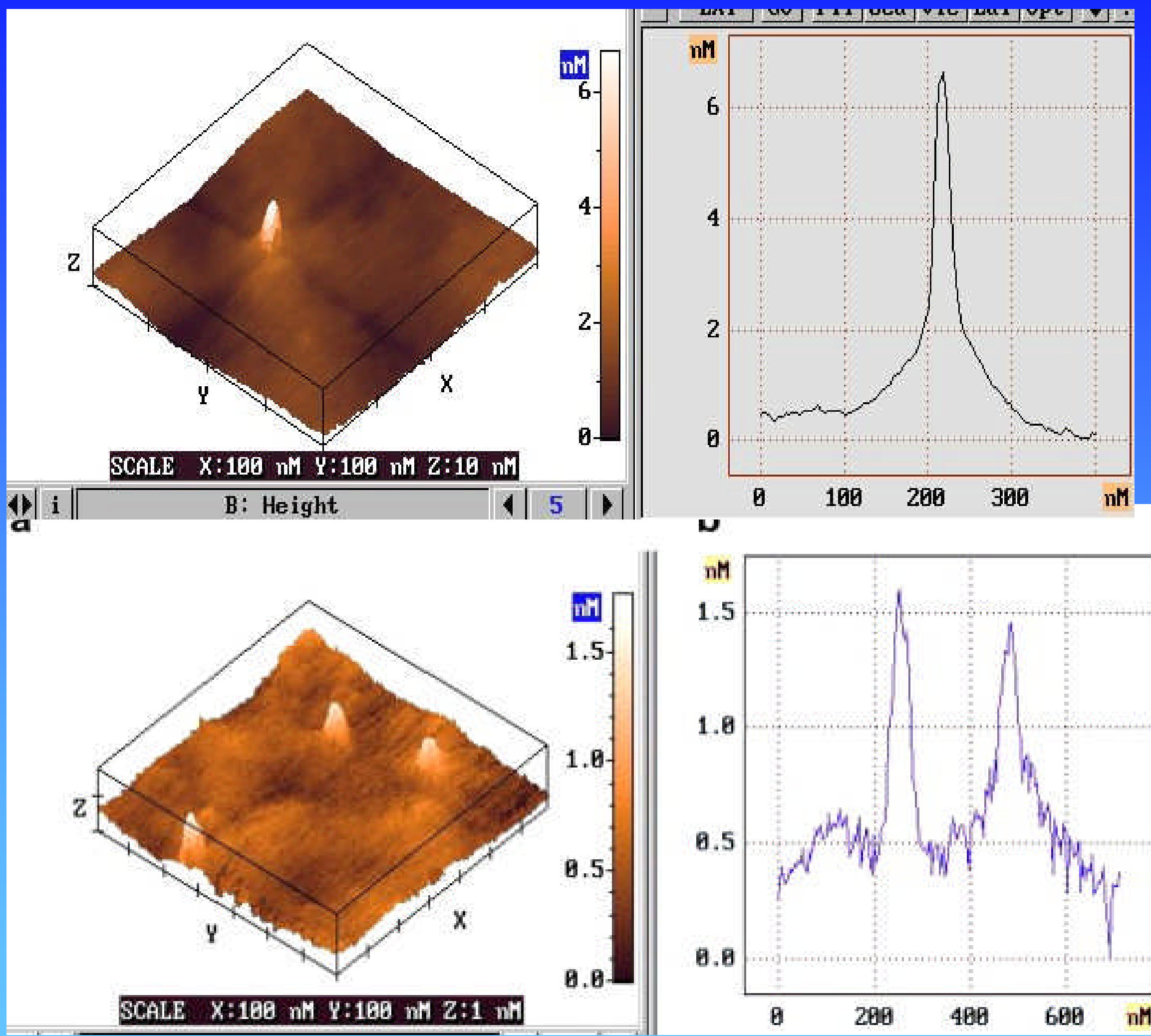
Xe gas natural

·Charge: 20+, 24+

·Ion flux: 1-100 ion/nm^2

·Extraction voltage: U= 4...10 KV

Surface structuring – AFM photos



$Xe^{20...24+}$

E= 120-240 keV

Production of surface micro and nanostructures in one step without etching

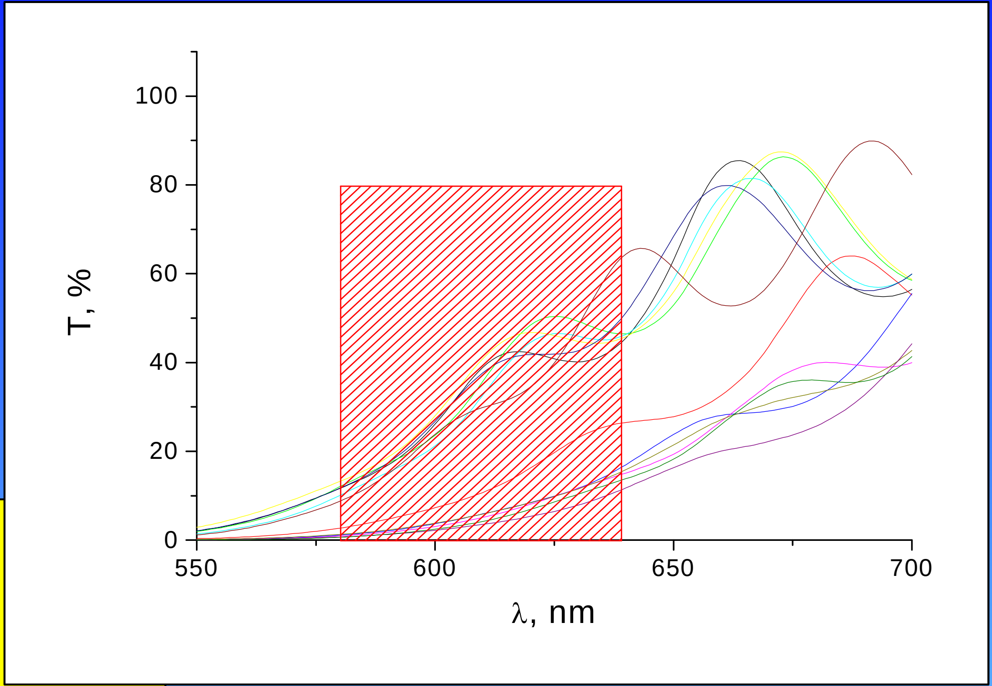
Hillocks!

One possible mechanism of nano-hillock formation consists in the process, similar to the radiation-stimulated creation and diffusion of defects to the drains at the surface.

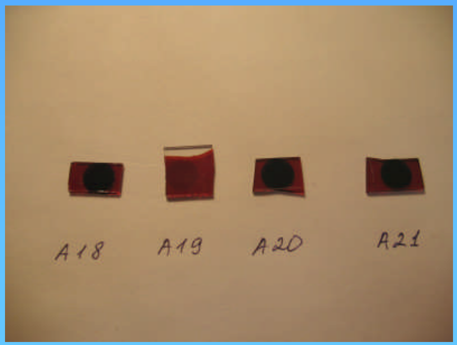
2007-2008: volume effects

Precedents

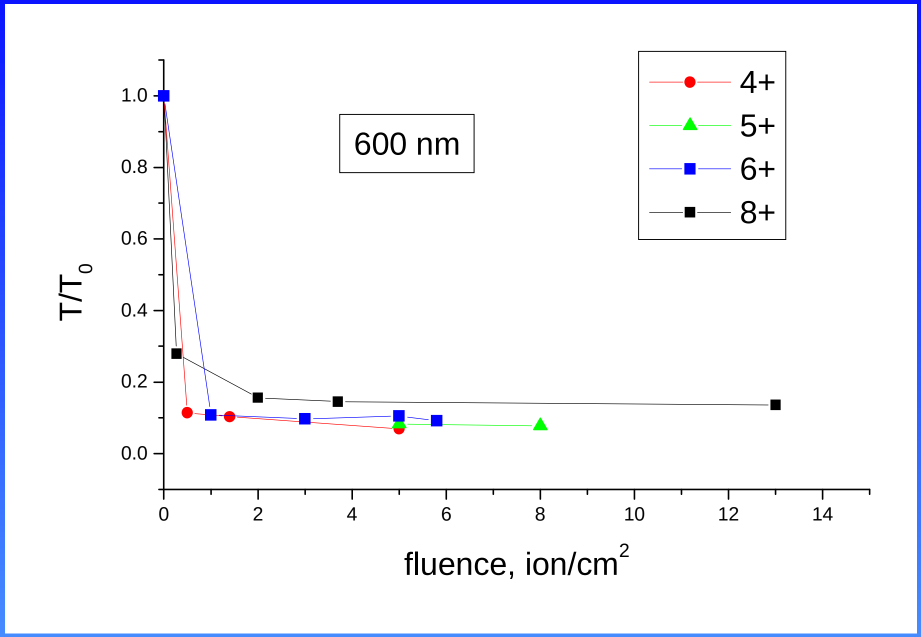
- Laser induced structural changes
- Ion irradiation induced structural changes (H^+, D^+)
- As_2S_3 , AsSe, Se

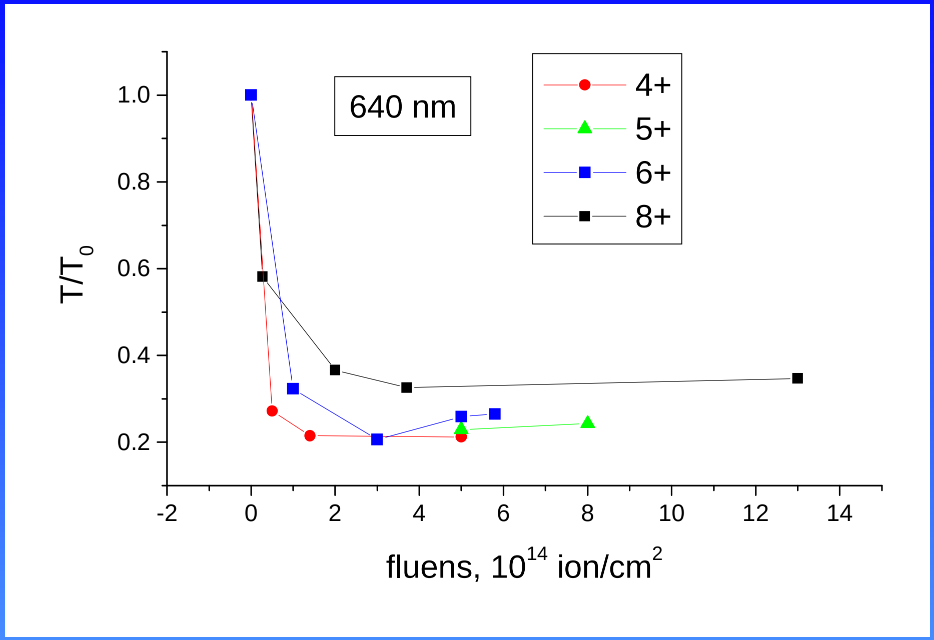


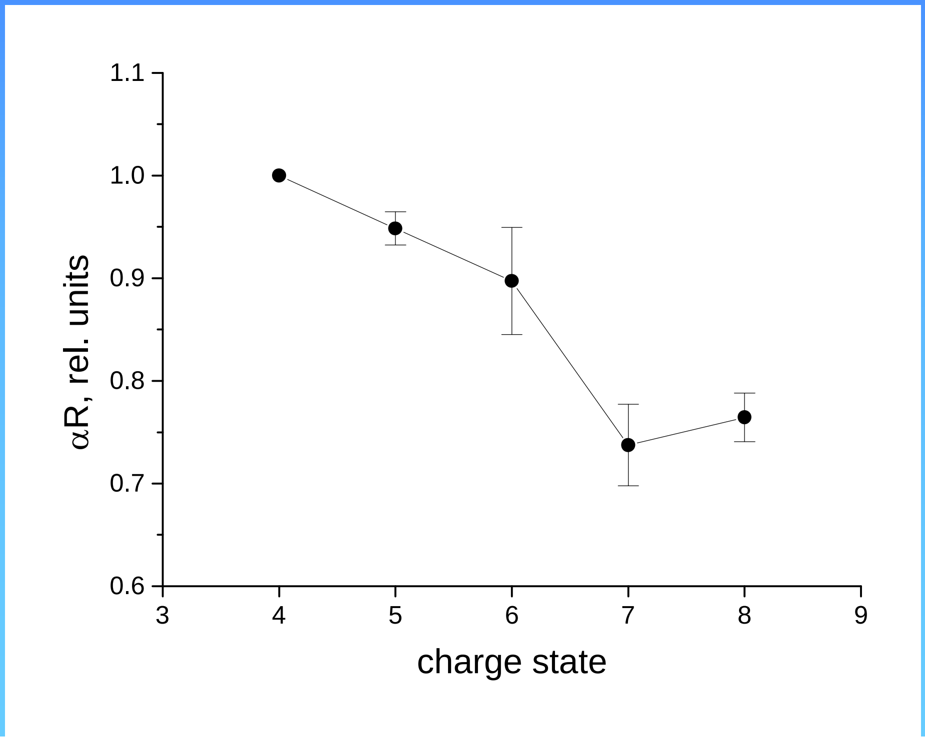
- Ions: Ne^{q+} (q=4...8)
- E_{kin}= 120 keV fixed
- Sample: AsSe layer on glass
- d=700 nm
- Penetration depth R= 200 nm
- Measured parameter: darkening (T/T_0) depending on the charge



$$T/T_0 = \exp(-ad) \approx \exp(-a_1 R)\exp(-a(d-R)) \approx \exp(-a_1 R) const$$





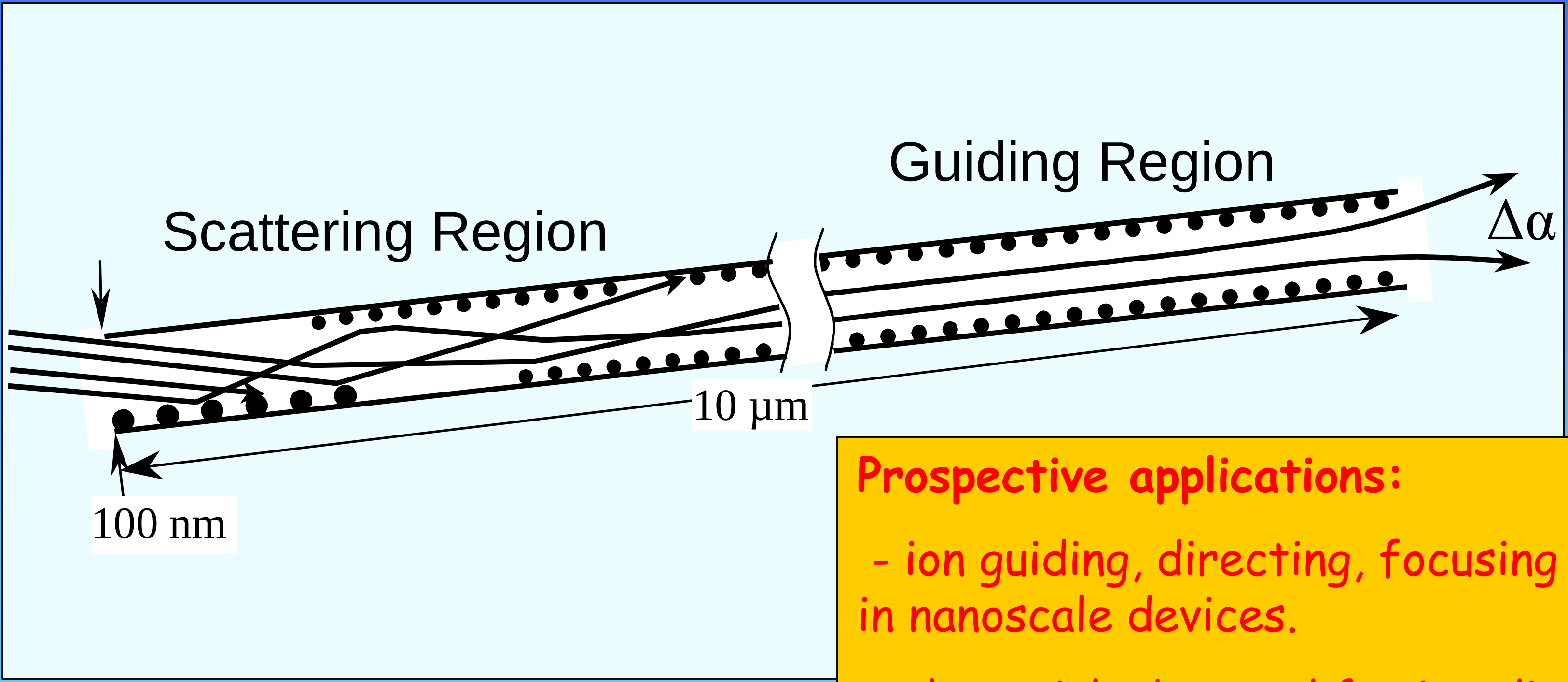


Our experiment showed that $(T/T0)_{sat}$ is larger for the sample irradiated with Ne8+ ions than for the one irradiated with Ne4+ ions.

Global optical property can be effected by the charge!

4. Guiding of slow, highly charged ions through nano-capillaries

- Ions with few keV energy have been transmitted through capillaries of thin PET and S_iO_2 insulating foils
- There was significant transmission even if the capillaries were tilted by large angles, i.e., when there is no geometrical transparency for straight line trajectories.
- The initial charge state may be or may be not changed.

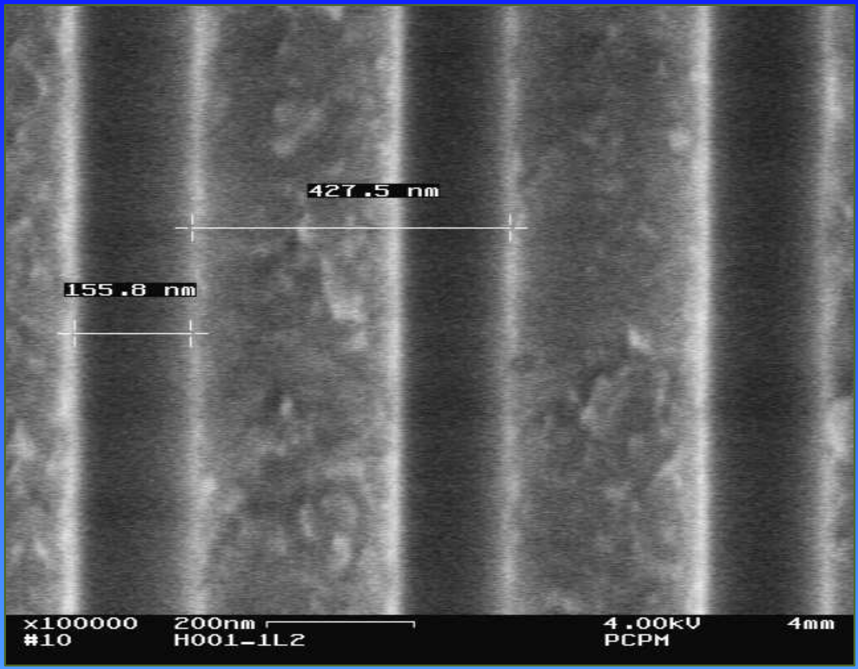


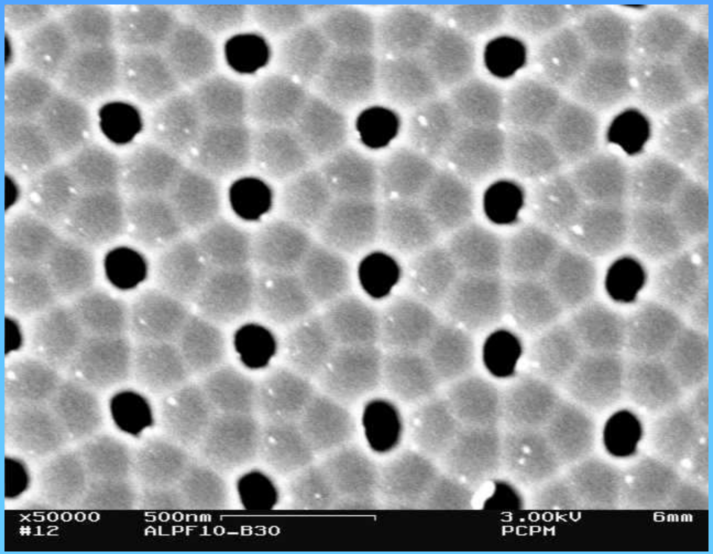
Prospective applications:

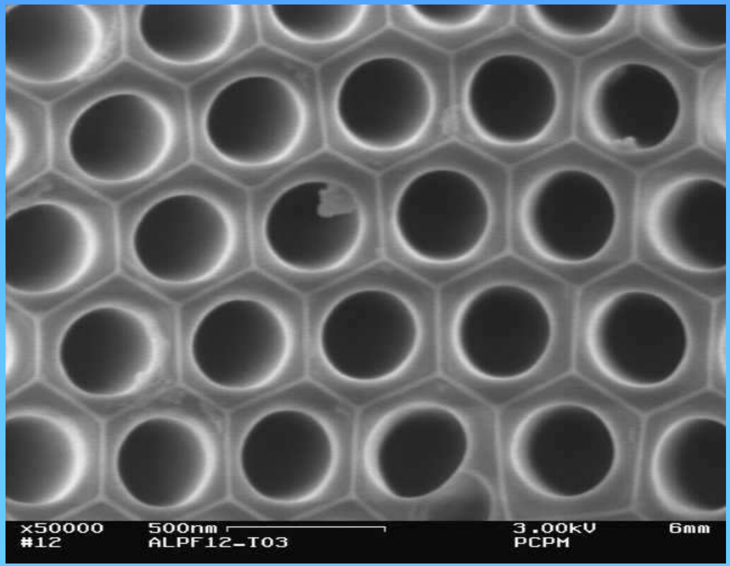
- ion guiding, directing, focusing slow ion beams in nanoscale devices.
- they might be used for irradiating single cells and writing on charge sensitive surfaces

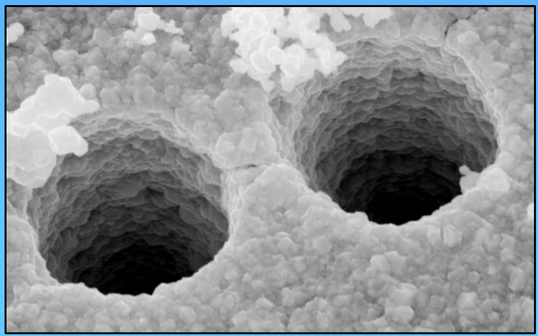
2004-2008: ATOMKI-ECRIS-A

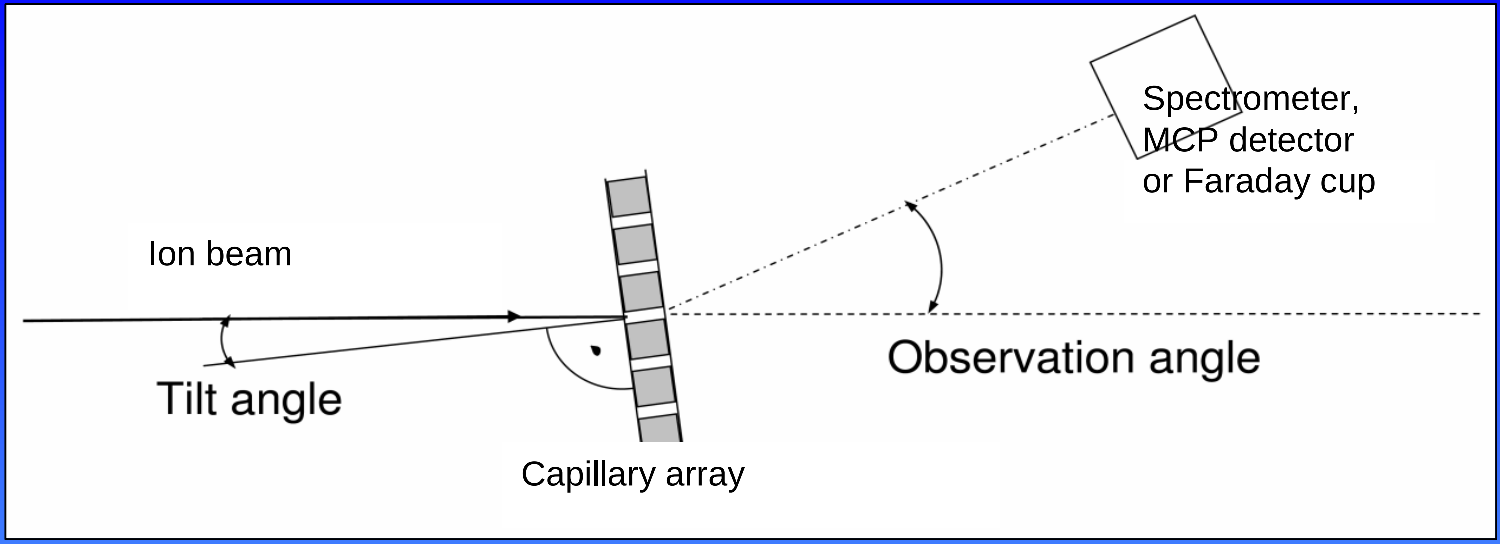
- Target: membranes of nanochanneled Al_2O_3, thickness 15 µm, honeycomb
- capillary diameters: 140-260 nm
- to prevent charging up: 20 nm Nb layers
- Neon (6+, 7+), argon (8+, 9+)
- Extraction: 500 V
- Beam: two 1 mm diaphragms at 205 mm
- Beam current 300-500 pA
- Detectors: FC, ion-spectrometer (channeltron), multi-channel-plate (MCP)



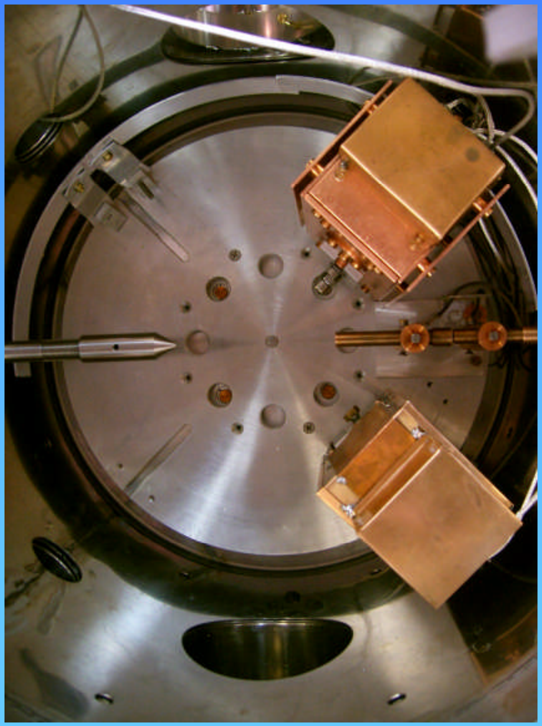


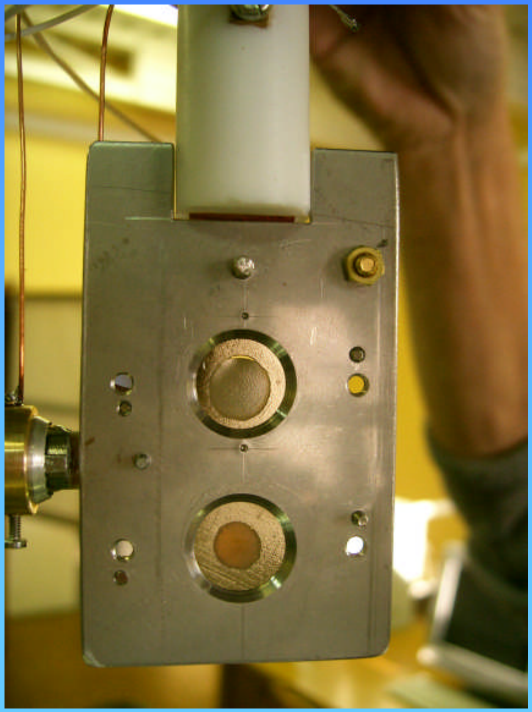




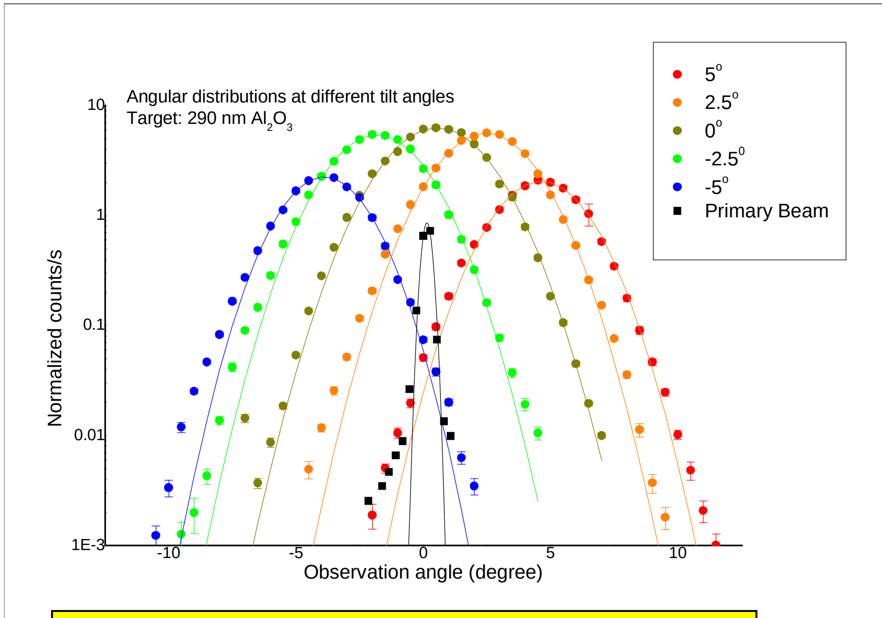


Experimental setup

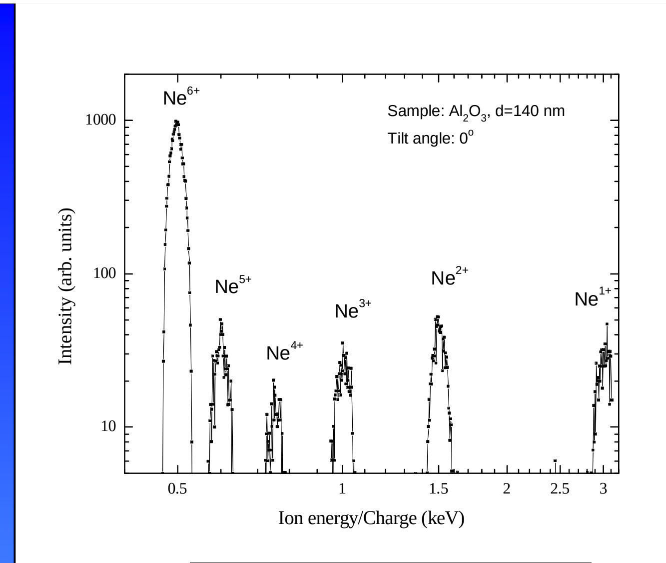




Results



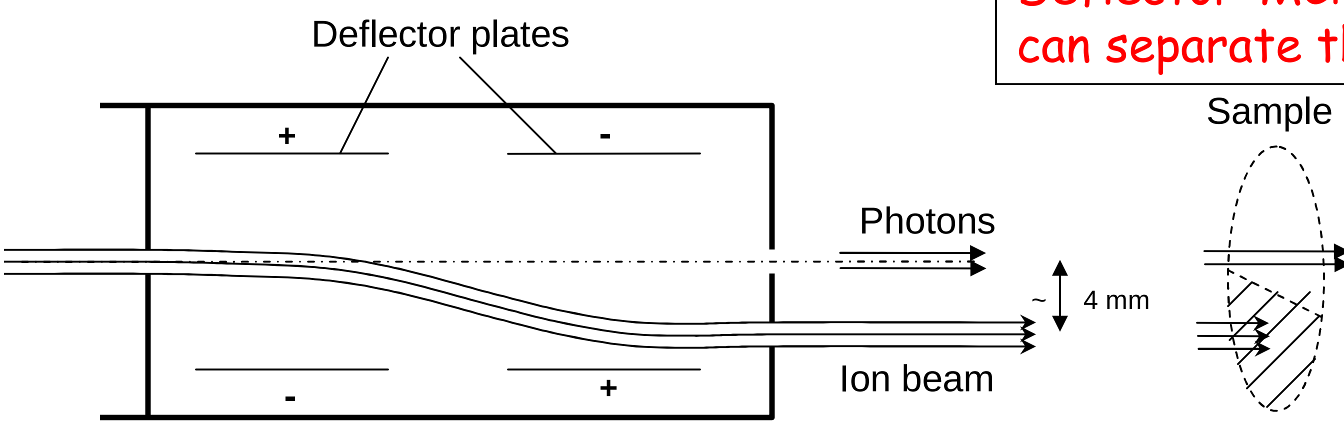
The capillary guiding works !

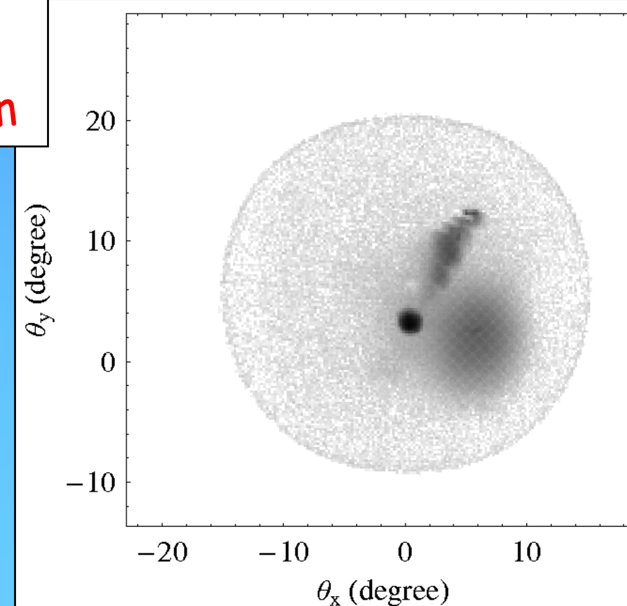


Ion CSD after the capilleries

UV photons were generated in the AM chamber

Deflector+MCP can separate them





Comparison and summary

Project short name:	Endohedral fullerenes	Ti implants coating	Thin layer modification	Capillary guiding
Ion source:	ATOMKI-ECRIS-B and Bio-Nano-ECRIS	ATOMKI-ECRIS-B	ATOMKI-ECRIS-A	ATOMKI-ECRIS-A
Plasma/beam:	Fe^{+}, C_{60}^{+}	C_{60}^{+}	$Ne^{4+\dots8+}$	$Ne^{6+,7+}$, $Ar^{8+,9+}$
Beam diameter (mm)	10-20	50	4	1
Extraction voltage (V)	500-5000	250-500	15000-30000	500-1000
Microwave frequency (GHz)	8-12	12-14	14.3	14.3
Microwave power (W)	1-50	4-20	200-400	200-600
Specification:	Synthesis in plasma or on surface	Irradiation in the zero-degree beamline	Beams with same total energy	Puller on high negative voltage

The tasks and beam requirements were different, but the ECR source proved to be versatile enough to fulfill all these jobs and serves as a very useful multi-purpose facility.

Thank you for your attention!