Структура и свойства металлических нанопроволок, выращенных в квантованных вихрях сверхтекучего гелия

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Москва 2010

New mechanism for impurities condensation in superfluid Helium

E. B. Gordon, Y. Okuda, JETP Letters, 85, 581 (2007), JLTP, 35, 209 (2009)

- Any guest particles have affinity to the core of quantized vortex.
- The particles captured there have enhanced rate of mutual collisions leading to coagulation.
- Resulting growth in its size increases the cluster lifetime in a vortex core and consequently their local density.
- Such self-accelerating catalytic process of condensation becomes to be prevailing .
- Due to the small (<1Å) thickness of a vortex core the primary condensation products should be extremely thin long filaments.
- Quantized vortex willingness of pinning to any protuberance may cause the filament growth just at needle electrodes

Образование металлических нанопроволок - лазерная абляция внутри HeII

Золото и медь – Fribourg (Швейцария)

Структура

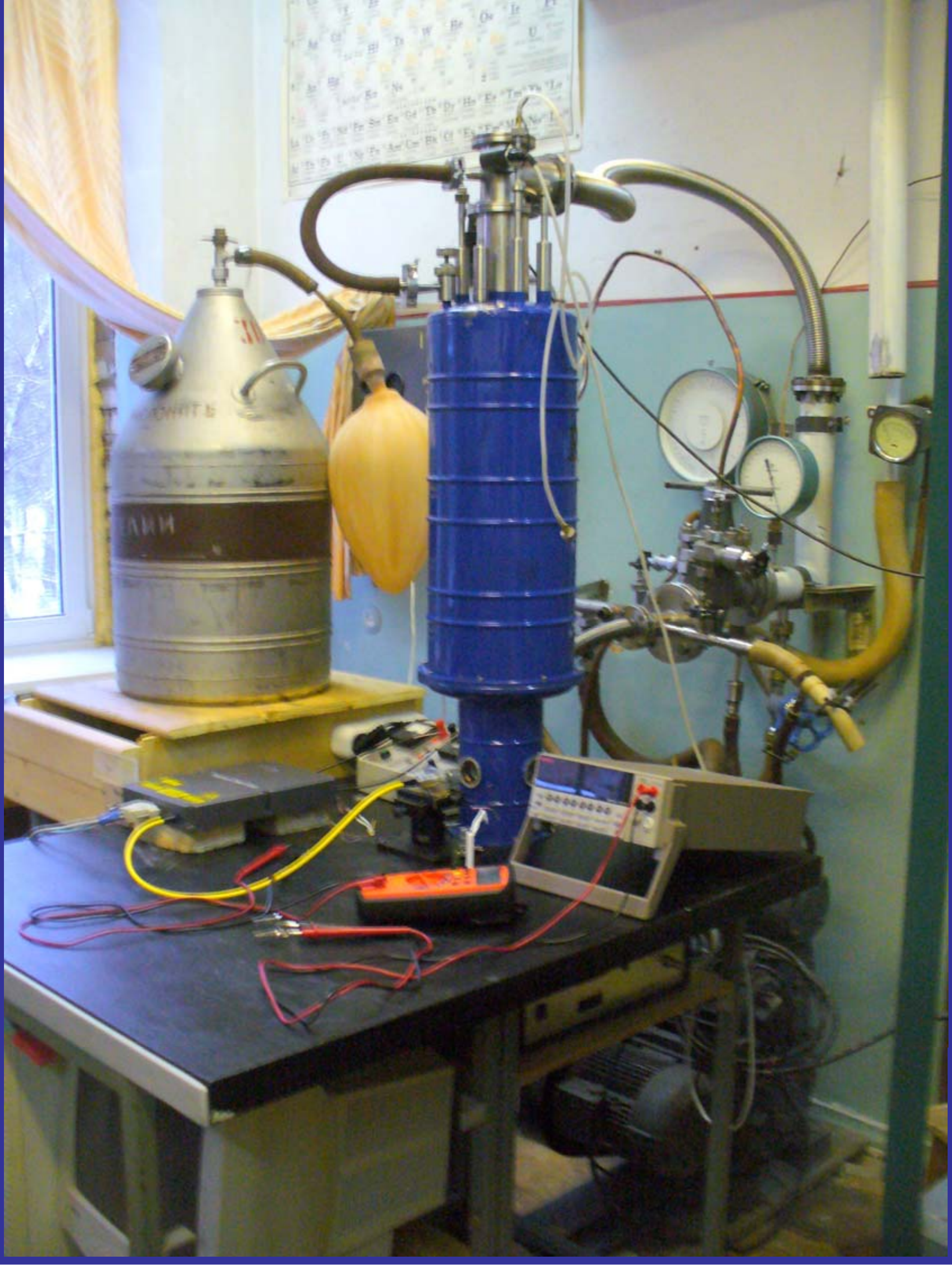
*P. Moroshkin, V. Lebedev, B. Groberty, G. Neururer, E.B. Gordon and A.Weis, EPL **90** 34002 (2010)*

Никель, индий, свинец и олово – - Черноголовка (Россия)

Электрические свойства и структура

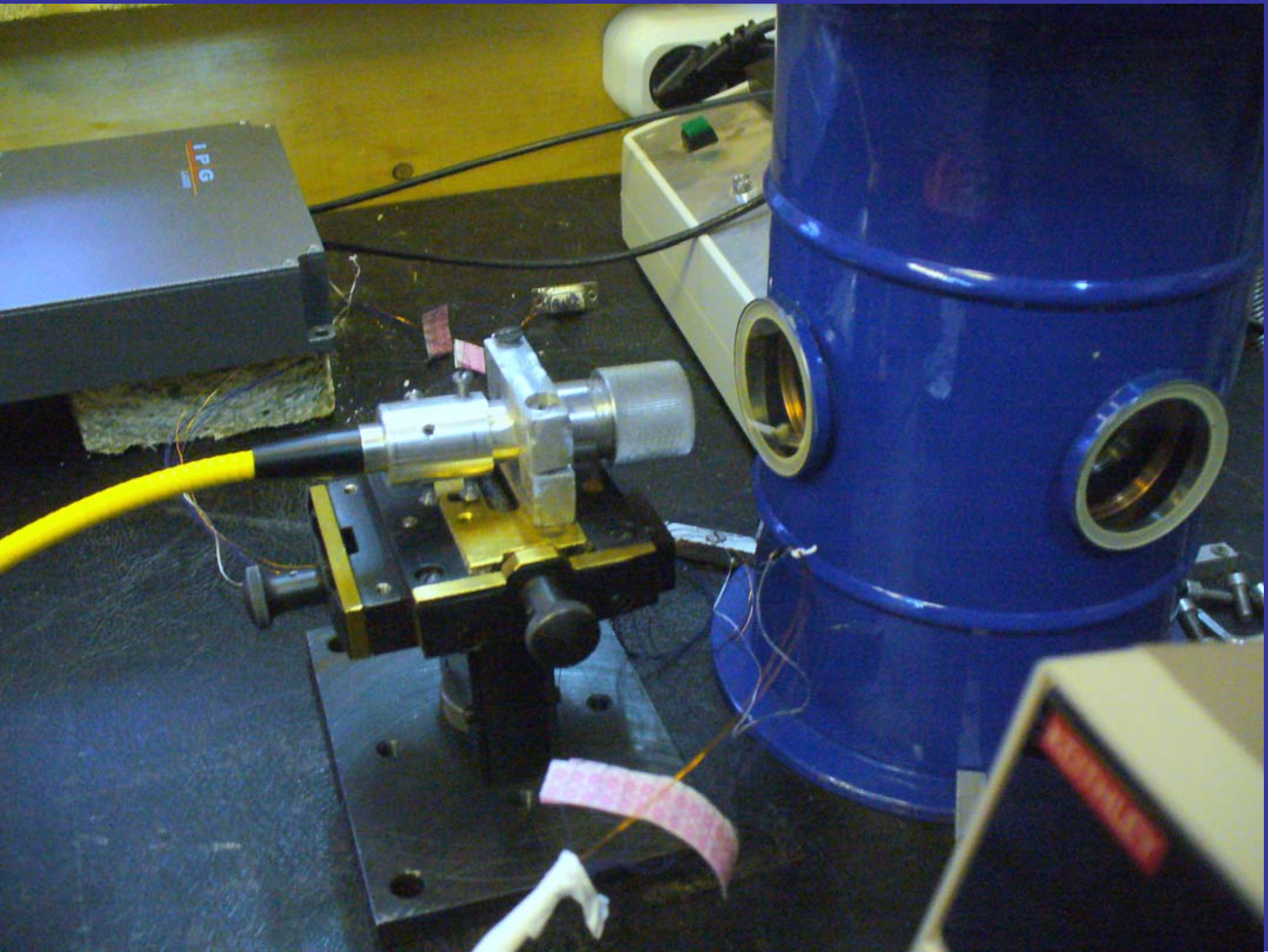
*Е.Б. Гордон, А.В. Карабулин, В.И. Матюшенко, В.Д. Сизов, И.И. Ходос. Физика Низких Температур, **36(**7), с. 740-747 (2010) .*

*Е.Б. Гордон, А.В. Карабулин, В.И. Матюшенко, В.Д. Сизов, И.И. Ходос. ЖЭТФ, **139(**4), (2011).*



Экспериментальная установка в ИПХФ РАН

Количество материала для изготовления нанопроволок столь мало, что можно использовать маломощный волноводный лазер



Иттербиевый лазер

λ= 1.06 μ

E = 10^{-4} J

τ = 25 ns

f = 0.5 – 2 kHz

Обычно падающие из места их образования

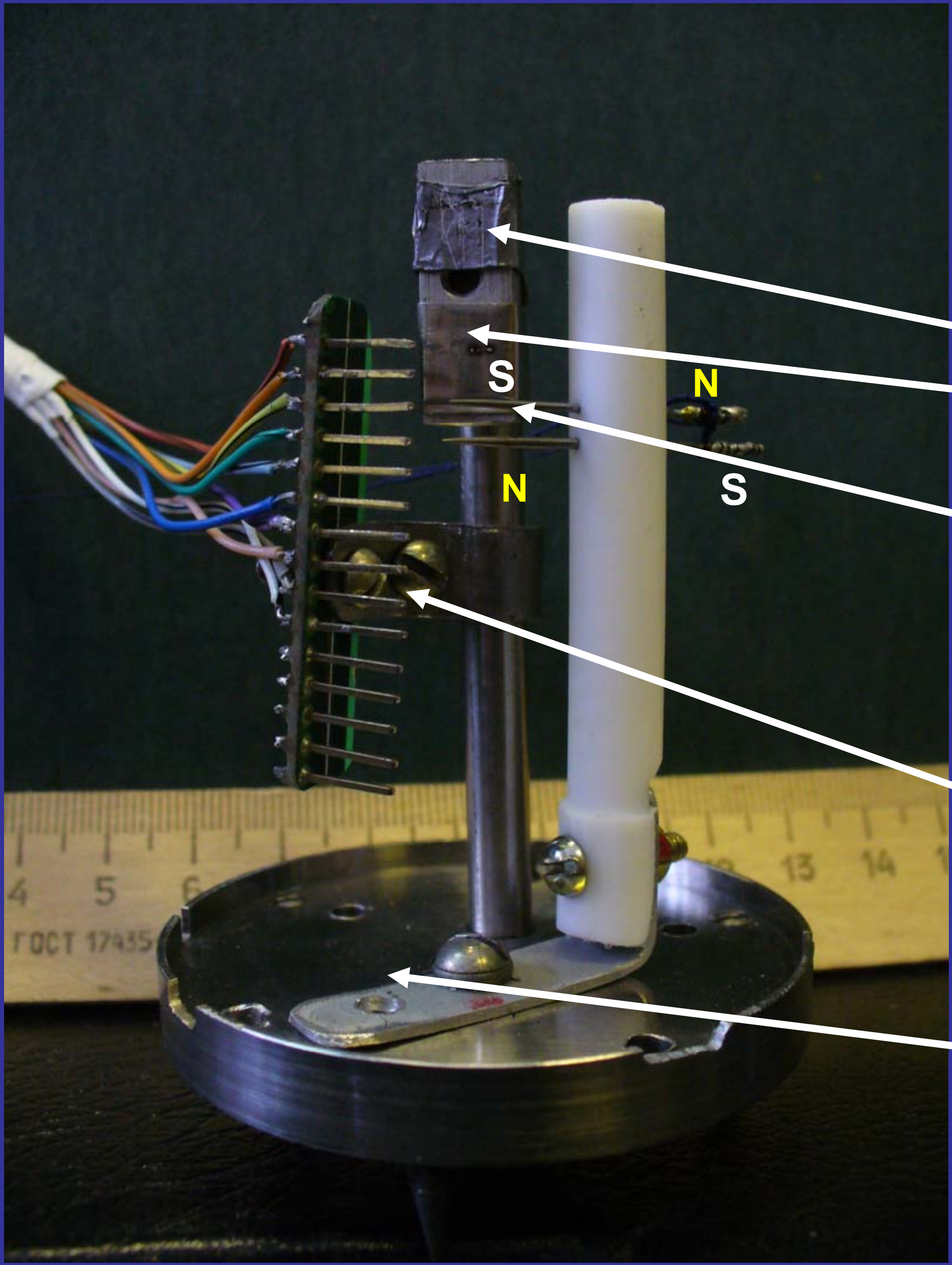
нанопроволоки пытаются поймать на решетку или сетку

При этом не удается создать надежный электрический контакт с электродами

Чтобы доказать способность нанопроволок прицепляться к остриям, мы использовали вертикальный ряд металлических контактов

При этом контакты оказались металлическими и прочными

Experimental cell



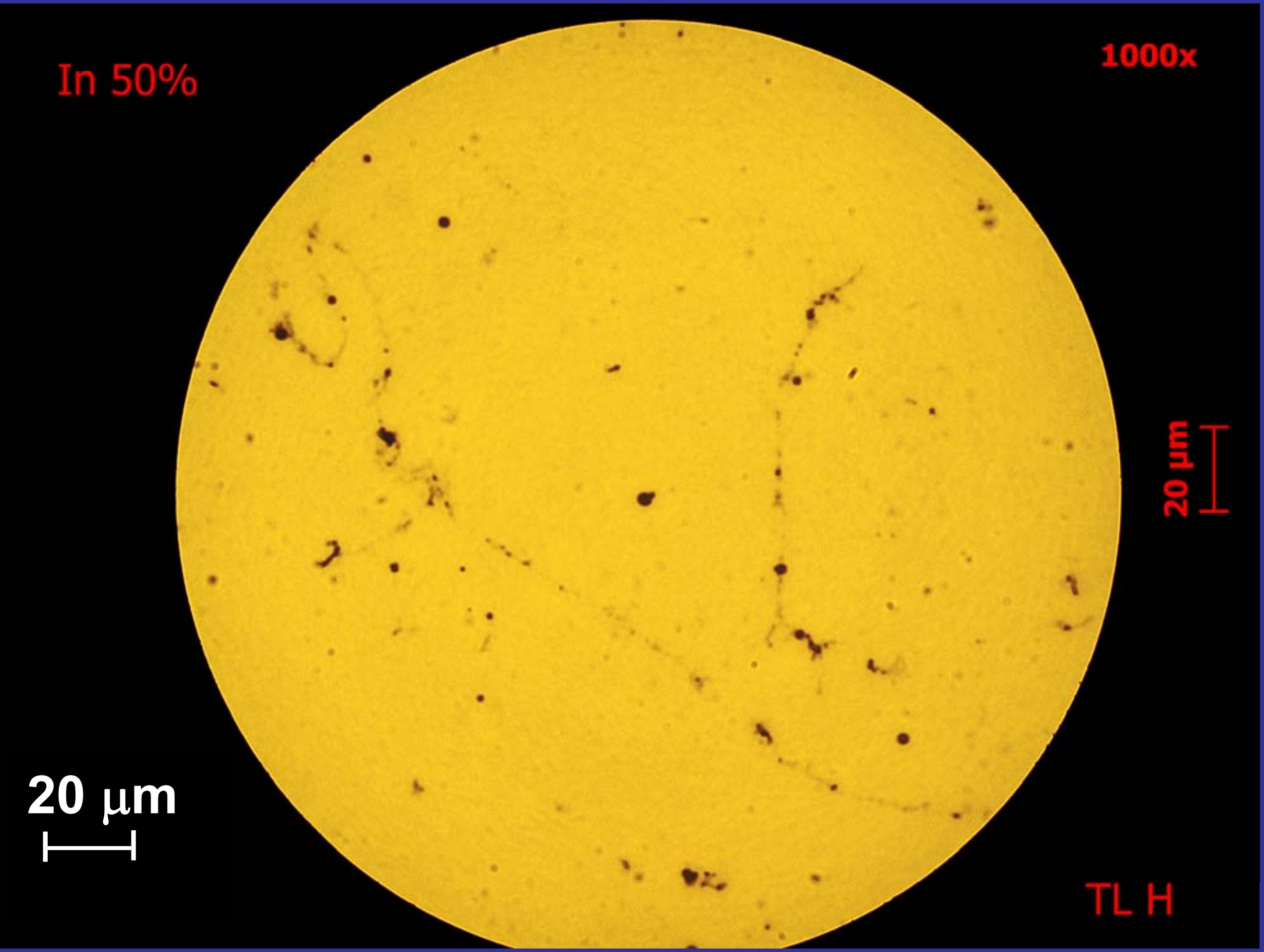
Metallic targets, the craters in laser focuses are seen

The pair of oppositely magnetized sewing needles are seen

Vertical row of gilded contacts, interelectrode distances are 3 mm each

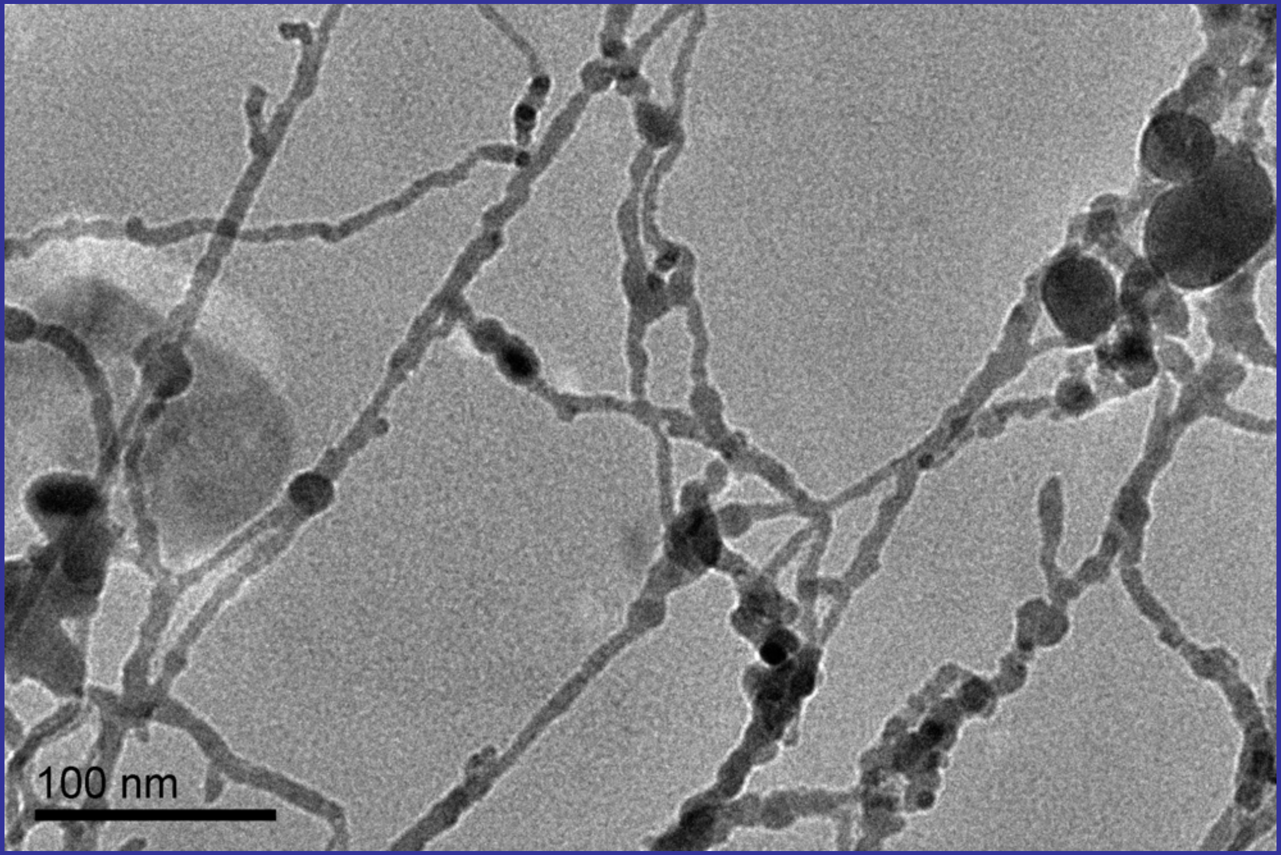
Bottom, where fragments of filaments where collected

OM: Sediment at remote area beneath of the electrode arrray



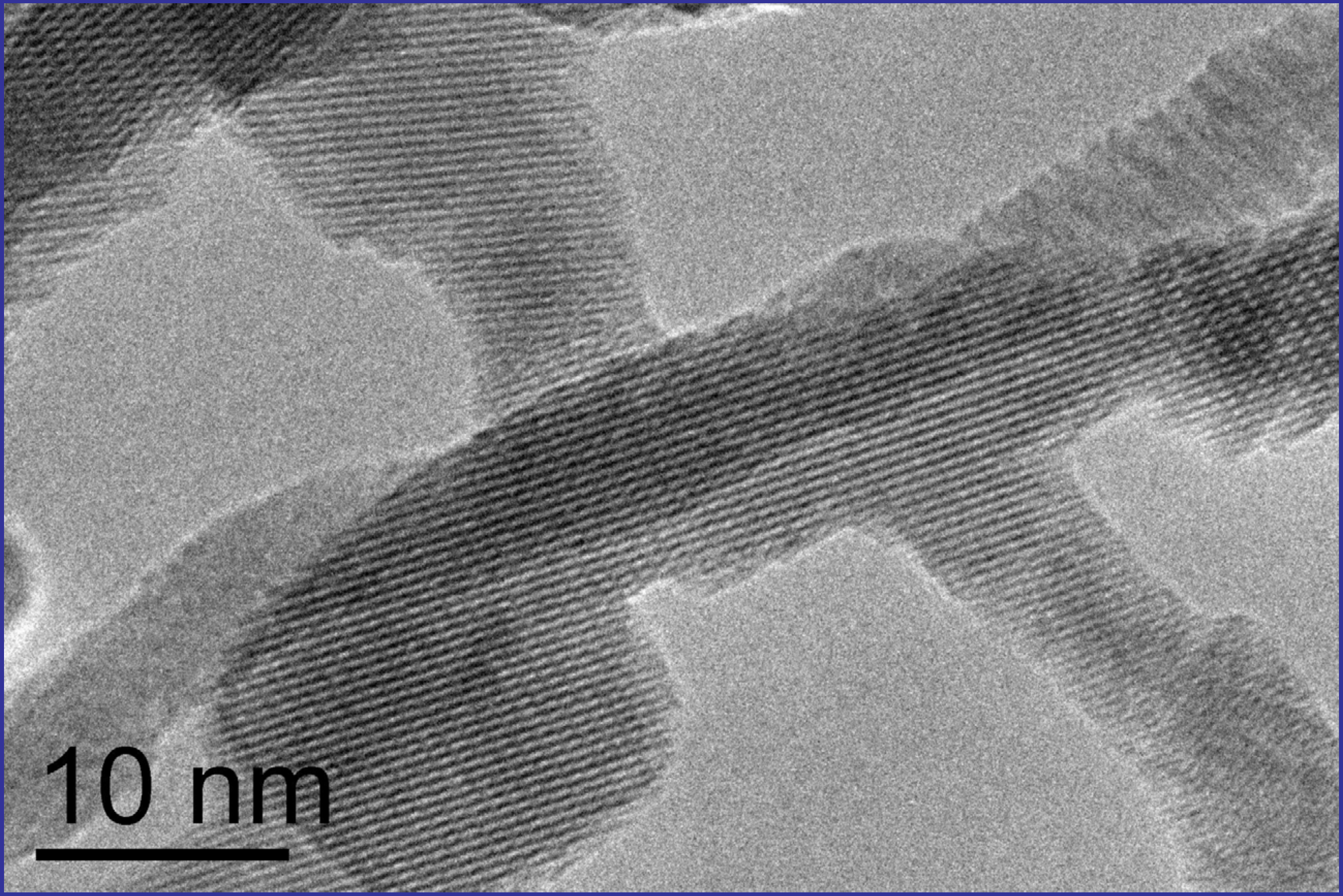
Compare with the length of common nanowires being about 1 micron

Fragment of Indium nanowire bundle (TEM)

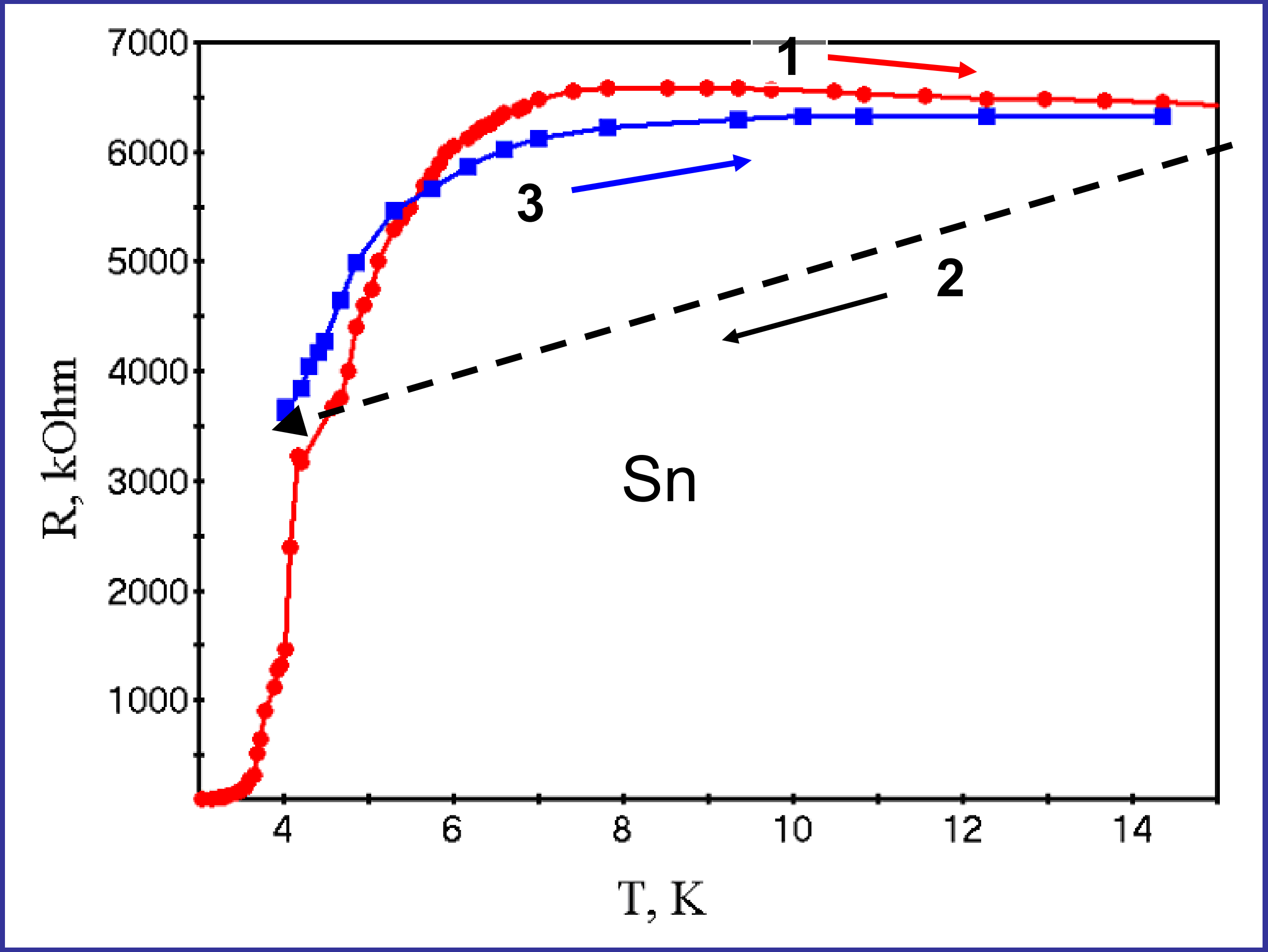


- **Rather thick – 8 nm in diameter**
- **Being inspected along individual wire displays monocrystalline structure**

Imposing the crystalline orientation in a knot (interference fringes direction and spacing)



The wires were monocrystals already in He II: reproducibility of transition from superconductive to normal state for bundle of tin nanowires (T_{bulk} = 3.7K)

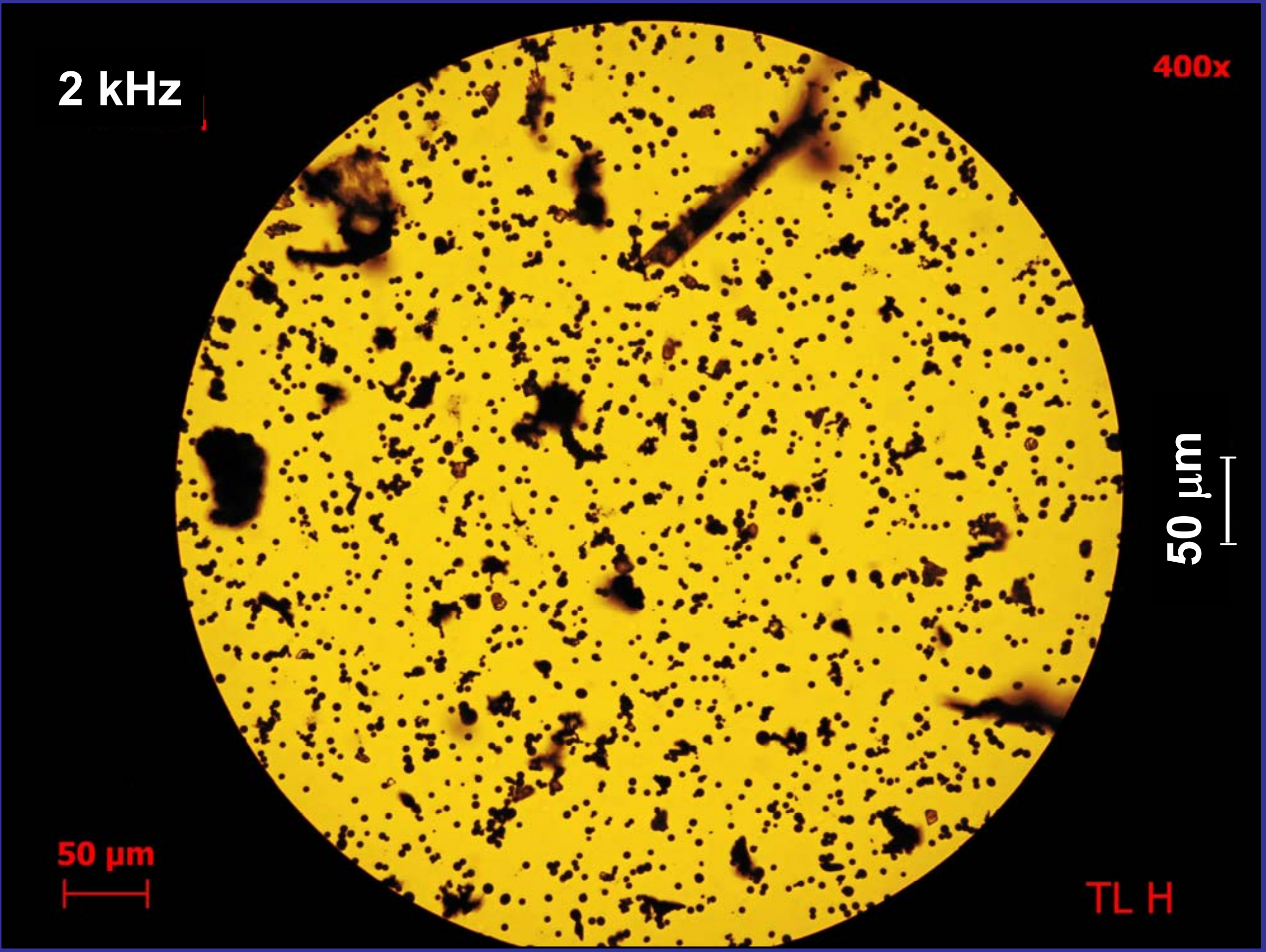


1 – passing λ-point, evaporating LHe, heating in a gas

2 – cooling down submerging into LHe

3 – repeated heating with LHe evaporation

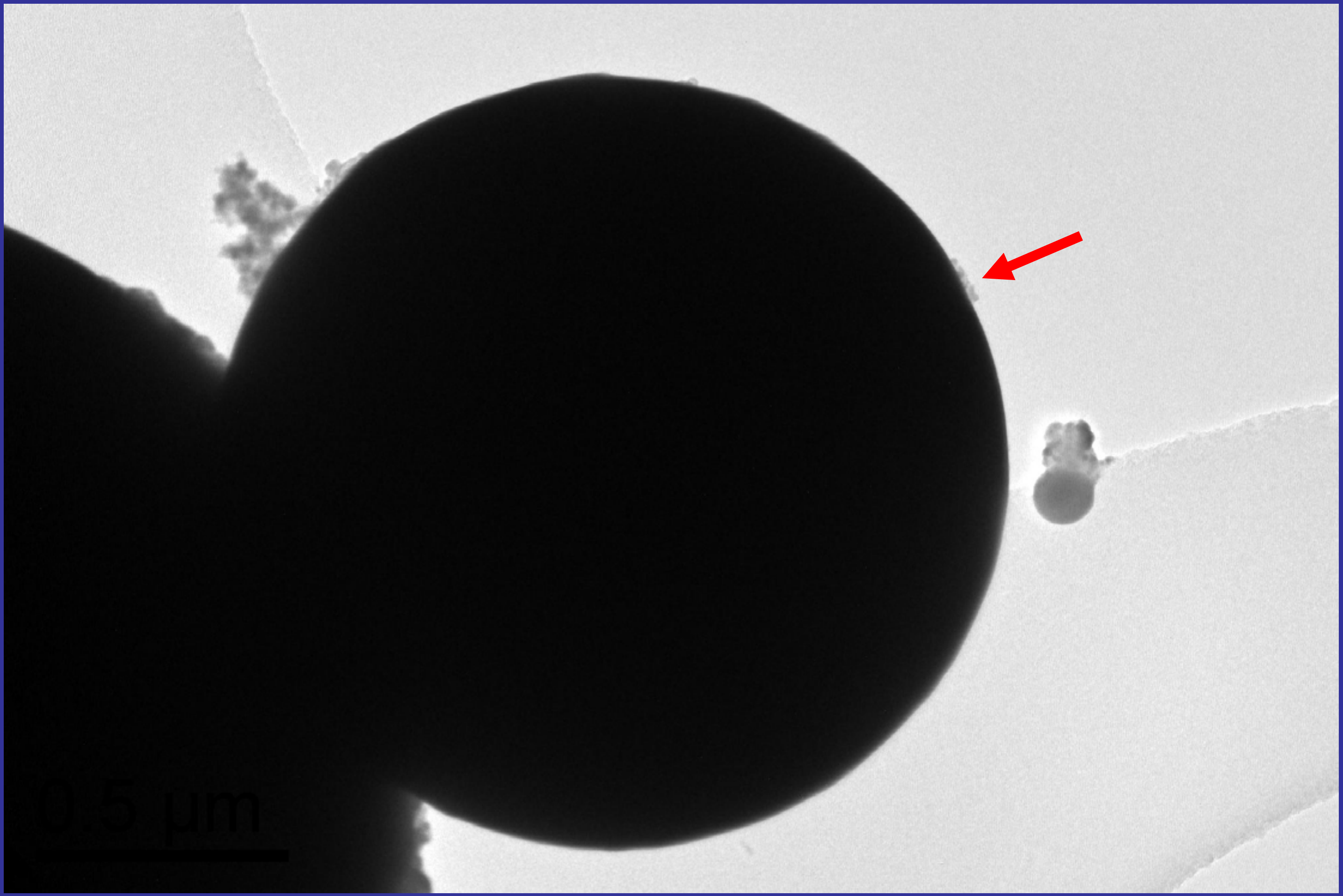
OM: Sediment just beneath the target



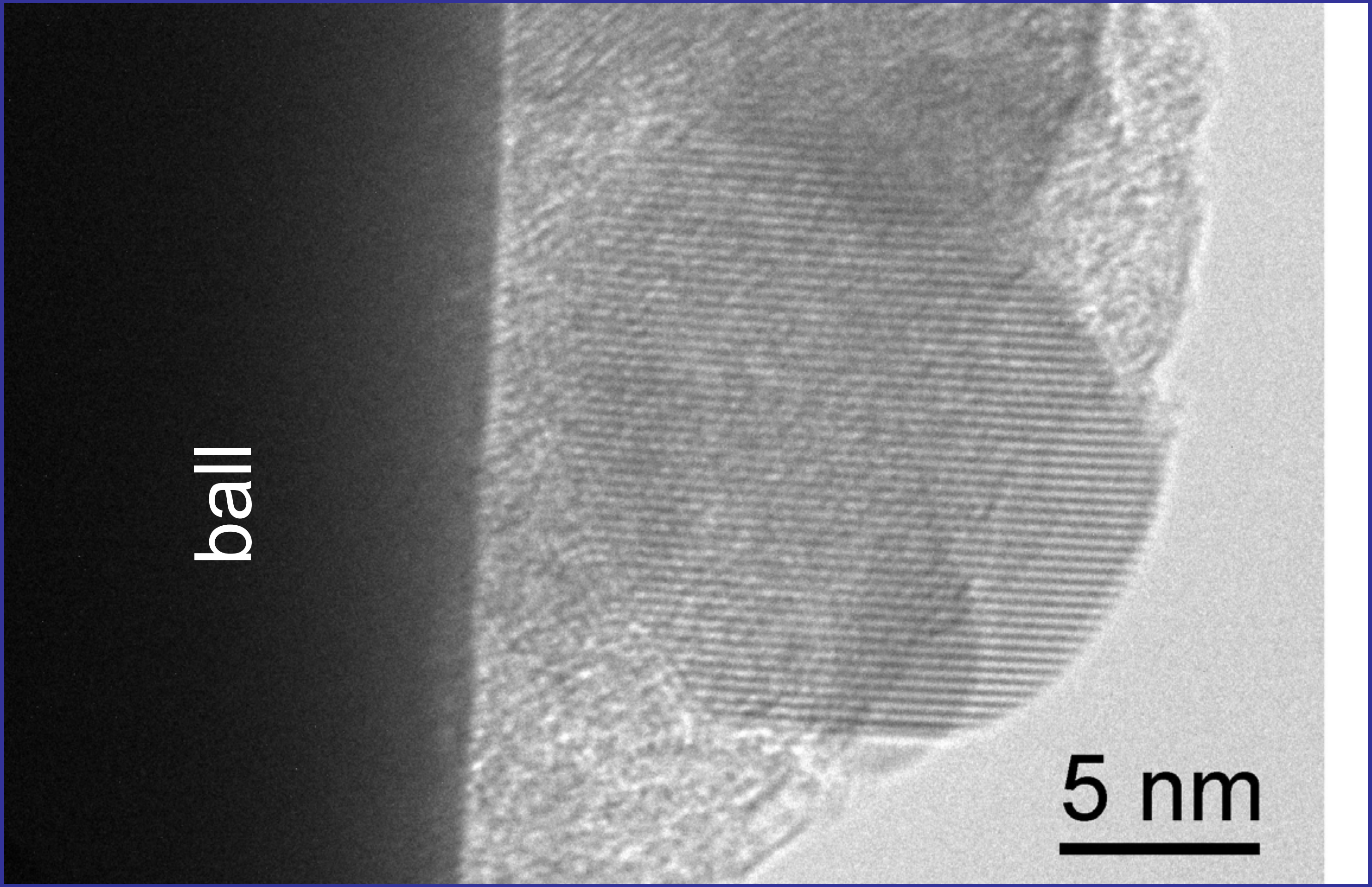
A lot of large (2 μm) metallic balls united to the beads –

possibly due to mutual repulsion as hydrogen large grains

The metallic balls are ideal spheres, their radius was grown with increasing laser repetition rate



The edge of this sphere at high resolution



Accidentally sticking to the ball microcrystal demonstrates the scaling, interference fringes have 3Å spacing

– the ball surfaces are atomically smooth

The unambiguous conclusion:
both wires and balls are formed through
molten state

In superfluid helium !!!

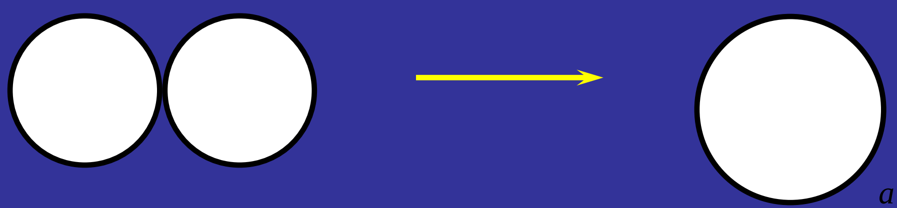
HeII "possesses thermal conductivity 200 times higher than Copper"

But for very weak heat flow – less than **$10\ W/cm^2$**;

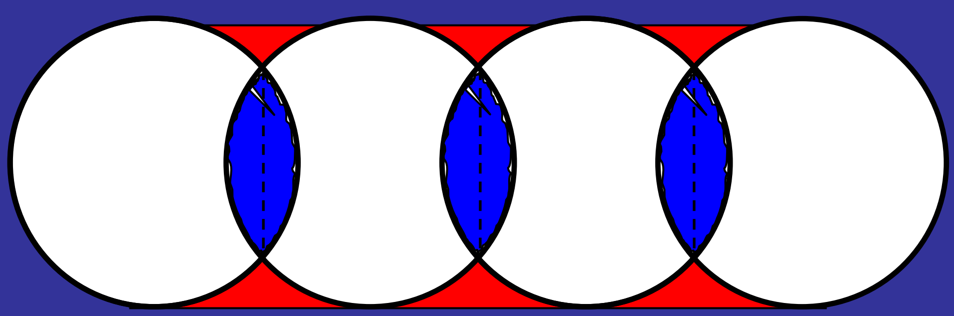
We should remove more than **$10^6\ W/cm^2$**

In adiabatic conditions small cold metallic clusters are known to melt at merging

Simple model for estimating limiting radius of liquid ball and wire



a – **one-layer thickness**



$$R \leq R_s^{\max} \equiv 0.78\alpha a$$

$$\alpha \equiv Q_b / (CT_b + Q_m)$$

$$R \leq R_w^{\max} \equiv \alpha a$$

Limiting sizes for melting spheres, R_s, and wires ,R_w

	α	R_s^{max}, nm	R_w^{max}, nm
In	7.66	1.8	2.3
Ni	3.05	0.7	0.9
Sn	7.12	1.6	2.1
Pb	4.34	1.0	1.3
Cu	3.28	0.78	1.0
Au	3.49	0.78	1.0
W	3.18	0.74	0.95
H_2	0.87	-	-
H_2O	0.77	-	-

In accordance with experimental results the radius of nanowire for casting metals is more than for refractory metals.

In hydrogen and water α <1 and melting is impossible.

- Нанопроволоки и наносферы получаются при условии, если исходные кластеры встречаются холодными.

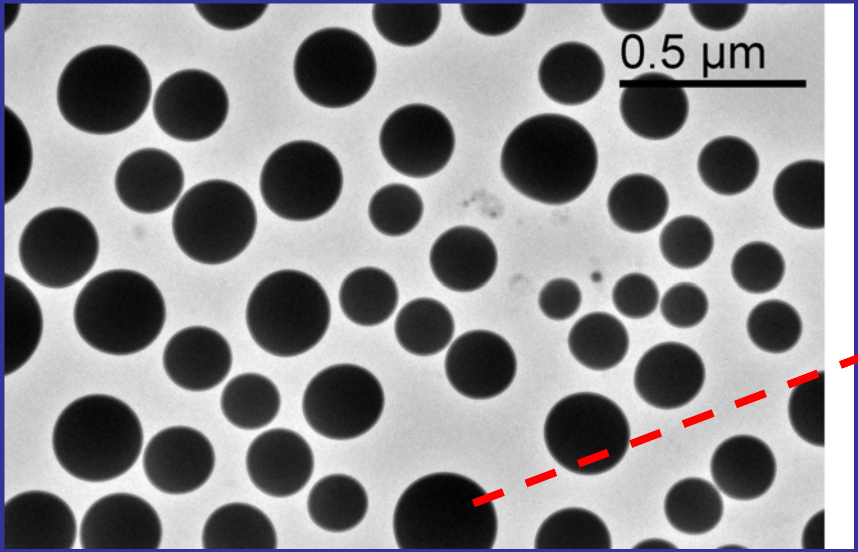
- Если интенсивность абляции велика и они успевают встретиться не остыв, ограничения на размер для плавления становятся более мягкими, а затем исчезают вообще.

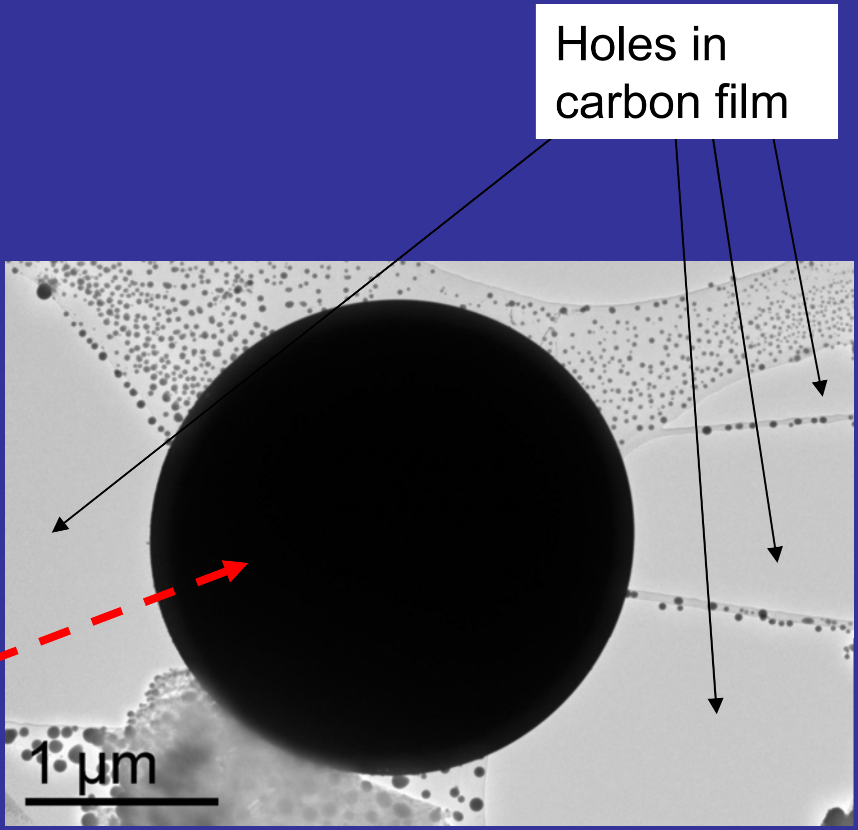
- Однако процесс коагуляции «больших» кластеров идет все равно в вихрях и лимитирующий их размер (около 1 мкм) определяется взаимным отталкиванием шаров в квантованном вихре

This interpretation found its support in very interesting observation

Sometime in TEM microscope (vacuum + T=300K) the ball exploded in a second after focusing electron beam on it. The negligibility of e-beam energy (ΔT_{av}= 0.2 K) was in a favor of its triggering action

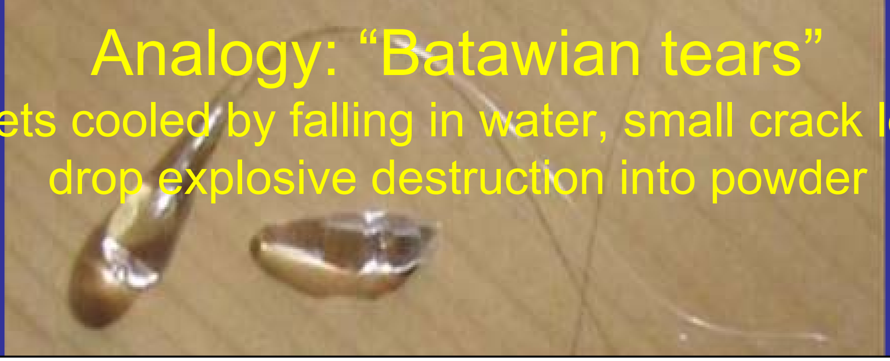
Exploding ball outthrows the hundreds of small spheres

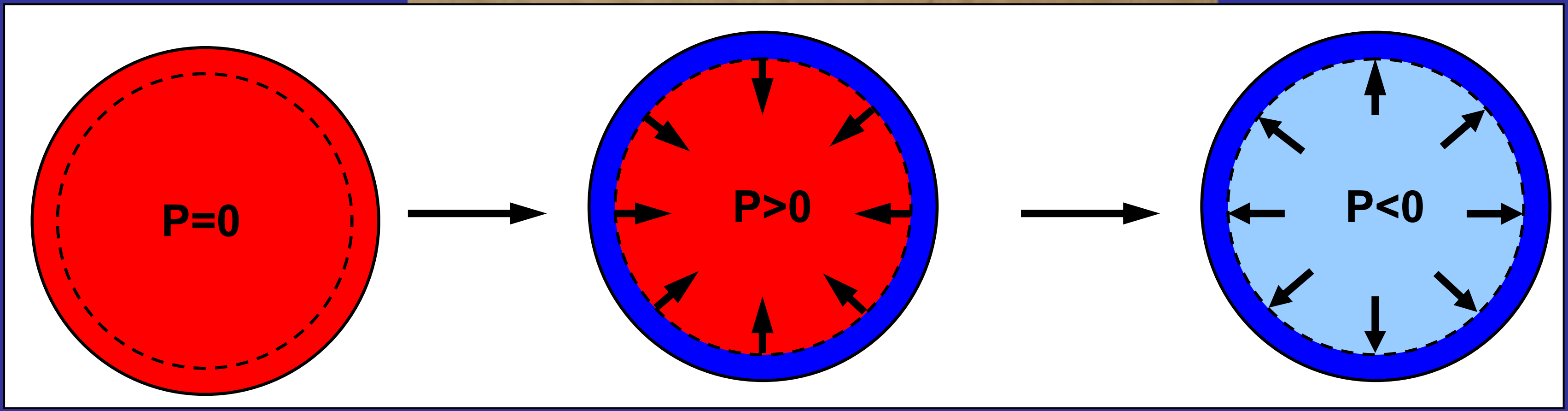




Analogy: “Batawian tears”

Glass liquid droplets cooled by falling in water, small crack led to the hardened drop explosive destruction into powder





Liquid hot drop size is higher then that of cold solid one

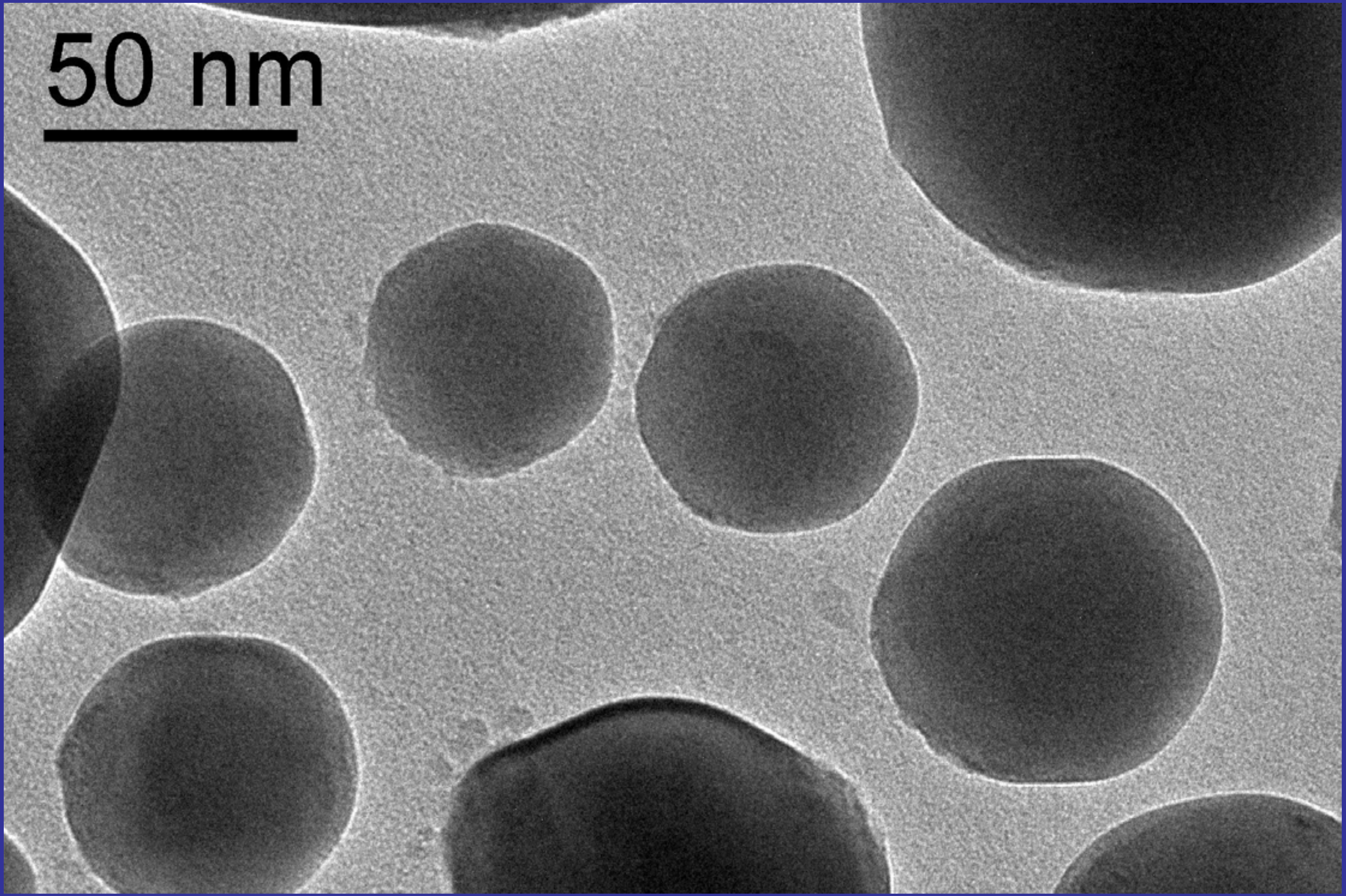
Fast cooling causes solid shell formation, which squeezed the liquid core

Further cooling leads to formatting solid core occupied the volume more then equilibrium one

The absence of dislocations and voids in micron-sized balls converts tensile metals, like indium,

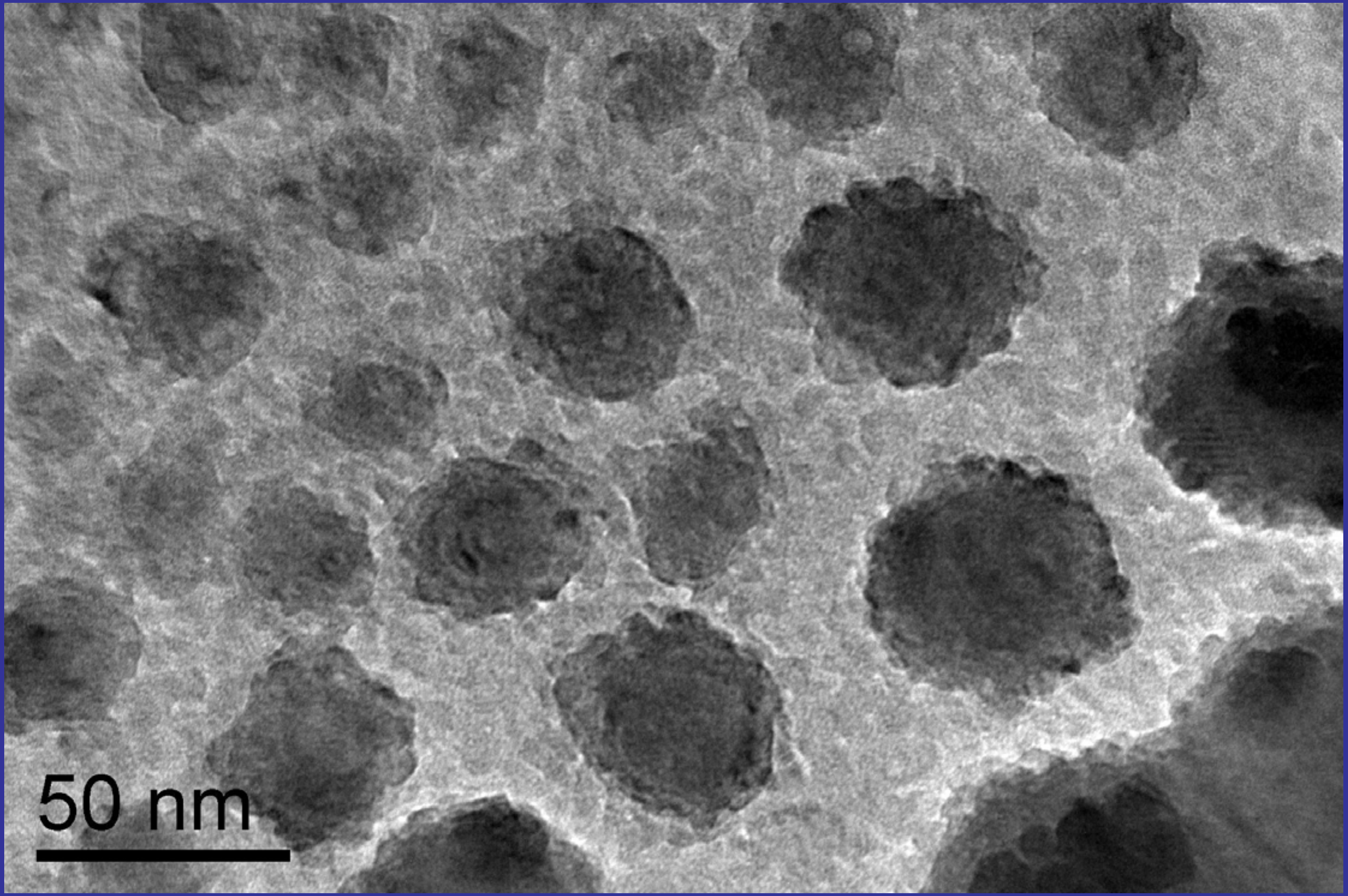
into hard elastic material as glass or steel

200 keV - electrons in TEM easily produce the microcracks inducing the decay



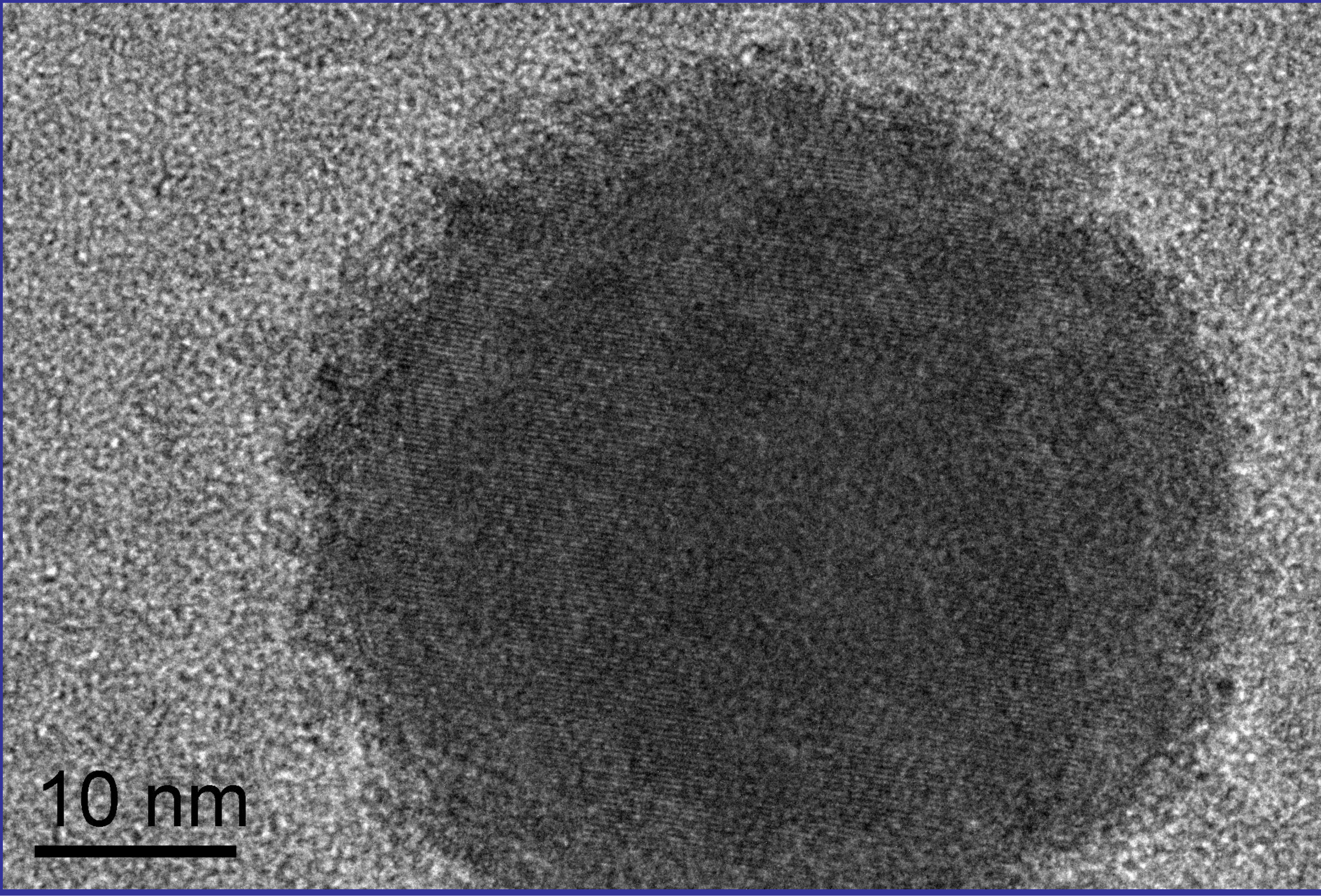
These small smooth monocrystalline spheres (quantum wells) are supposed to be the product of merging in vacuum of much smaller pieces

What was the size of primary dust particles formed in “tear” explosion ?



We were lucky to find the balls displayed threshold behavior, when the dust was too large to become molten under sticking. The dispersion of dust on size is rather narrow, because all of them are similar

This protostar was definitely composed from crystals of 6 nm in diameter , interference fringes are seen



Conclusion

- Production of long thin metallic nanowires and strained metallic atomically smooth spheres was demonstrated in HeII, both of them displayed monocrystalline structure.
- The lowering ablative laser intensity was proved to improve quality of nanowires.
- The growth of HeII SVP from 10^{-2} to 25 bar should significantly diminish the yield of metallic balls comparatively to nanowires.
- Strong size effects inherent to electrical properties of nanowires have been demonstrated.