Focused Electron Beam Induced Processing (FEBIP)

is a technology to develop and produce with single electron beam systems (cost 1.5 Mio€) short wires and several novel products, like for conduction of high currents without Joule's heating, for applications in electrical machines, electronics, computers, power distribution, for large area deposits for catalysators and photo-detectors, as well as for very high efficiency solar cells (3 x Si solar cell efficiency!) in small quantities and at high cost. **Miniaturized Field -Electron sources deliver electrons at voltages below 100 V and up to 1 mA current for electronics,** high speed switching amplifiers, high power sources for IR, THz- (up to 10 THz and 1 W) and X-Rays, switchable sources for brachy-therapy, high current switching, high resolution detectors and sensors for IR, Vis, UV and EUV , detectors for X-ray tomography and phase contrast X-ray imaging.
The construction of self reproducing miniaturized optics for massive parallel particle optics application of scanning- electron- and -ion-microscopes for the semiconductor industry becomes possible**. With such specially developed adapted multiple beam production machines many novel products can be produced in an economic way**, like large area sheets for catalysators, solar cells, high resolution detectors, long power distributing cables, low voltage high current switches , field-emitter lamps with 65 % efficiency!!, and many more optical and electronic metrology devices.

Koops-GranMat® can revolutionalize the electronic technology in a dramatic way, with the capability of 100 times of what superconducting materials can do, but with the advantage to operate at room temperature and having no need for expensive cooling systems.

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Koops –GranMat® - Name protection in EU, April 2014
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M. Remeika, M. M. Fogler, L. V. Butov, M. Hanson, and A. C. Gossard, Two-dimensional electrostatic lattices for indirect excitons, arXiv:1109.6659v1 (2011), Appl. Phys. Lett. 100, 061103 (2012).
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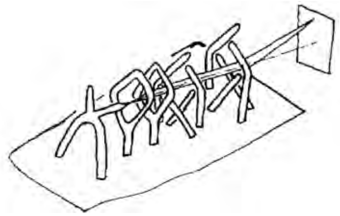

With FEBIP produced Koops-GranMat® has a Bose-Einstein Condensate at 300K, and is good for a revolution in electronics, energy harvesting and distribution, signal processsing, lighting, medical imaging and photon detection

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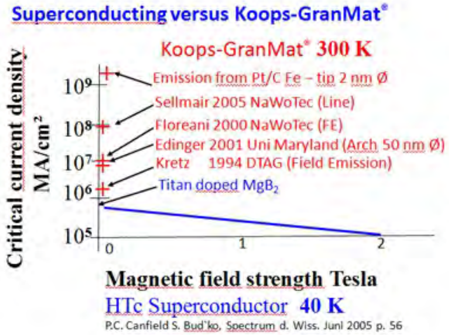
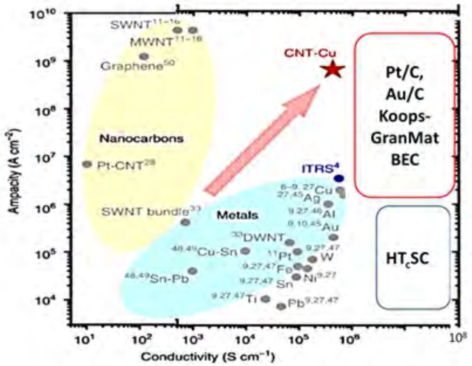
www.hawilko.com
Ober-Ramstadt, 11.10.2014

Giant Current Density in Koops-GranMat® and anomalous high currents result from a Bose-Einstein Condensate at Room Temperature

Material	Current carrying capacity (MA/cm^2)		Reference
Au/C, Pt/C Koops-GranMat® Field-emitter	>1 GA/cm^2	1 mA / <10nm □emitter top	Kretz (1994) Au/C
	>13 MA/cm^2	10 □A / <10nm □emitter top	Schoessler (1998) Pt/C
	20 MA/cm^2 >1 GA/cm^2	1.3 mA / 80nm □emitter rod center, <10nm □emitter top	Floreani,.(2001) Pt/C
CNT	< 1 GA/cm^2	< 100 nA for a single mw/CNT	Wei, et al. (2001)
CNT/Cu	600 MA/cm^2	hybrid material for increasing conductance of CNT to that of Cu	Subramaniam, et al. (2013)
High-Tc super-conductor	1 MA/cm^2	Ti/MgB2 @ 40K & zero magnetic field	Scientific American (April 2005)
Au Cu	<250 KA/cm^2 < 2,5 KA/cm^2	Limited by electro-migration Limited by electro-migration	





Comparison of critical current densities for destruction for High TC Superconductors at 40 K, and of experiments using Koops-GranMat® materials at room temperature.
HTC superconductors get destroyed at current densities above 1 MA/cm².

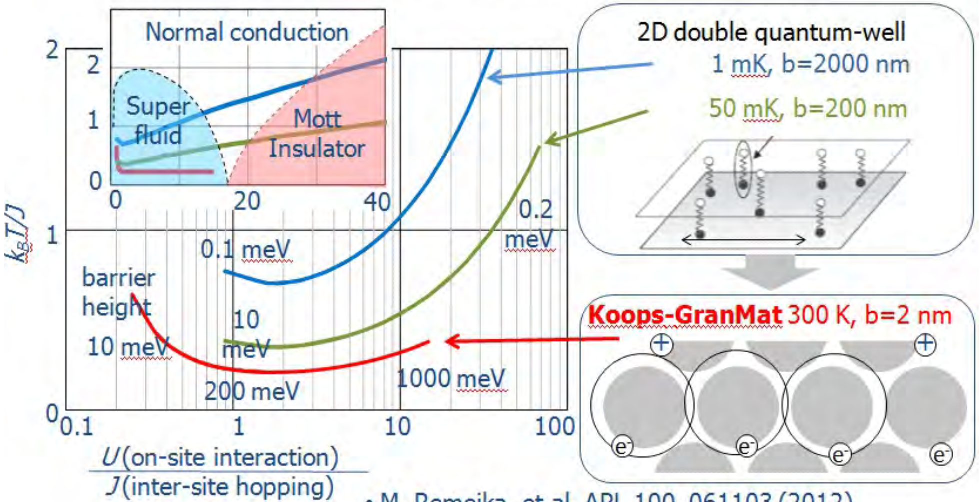
Koops-GranMat stands > GA/cm² in FE-tips.

Comparison of current density carried by CNT, Graphene, Metal fiber filled Graphene, HTC – Superconductors at 40 K and of Koops Gran Mat Au/C, Pt/C NMG at Room temperature.

★ Source: *Chandramouli-Subramaniam et al. Fig. 1 c, Nature Communications Vol.:4. 2202, 23.7.2013*
P.C. Canfield , S.. Budco, Spectrum d. Wiss. Juni 2005 p.56

Excitonic Quantum Condensate

Orders of magnitude smaller dimension and higher density compared to conventional systems which are used in excitonic BEC research

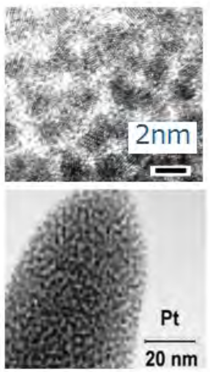


• M. Remeika, et al. APL 100, 061103 (2012)

Koops Gran Mat® surpasses all known materials in carrying giant current densities and anomalous high currents.

■ Materials and processes

•FEBID Pt/C



■ Electronic, emission, thermal characteristics

- 1GA/cm²
- Negative slope of resistivity vs. temperature by Variable Range Hopping
- Photo-response
- Coherent electron emission in field emission

■ Charge transport mechanism

- Surface orbital exciton cluster model
- Charge transport mechanism by excitons
- e-h quantum condensation at Room Temperature

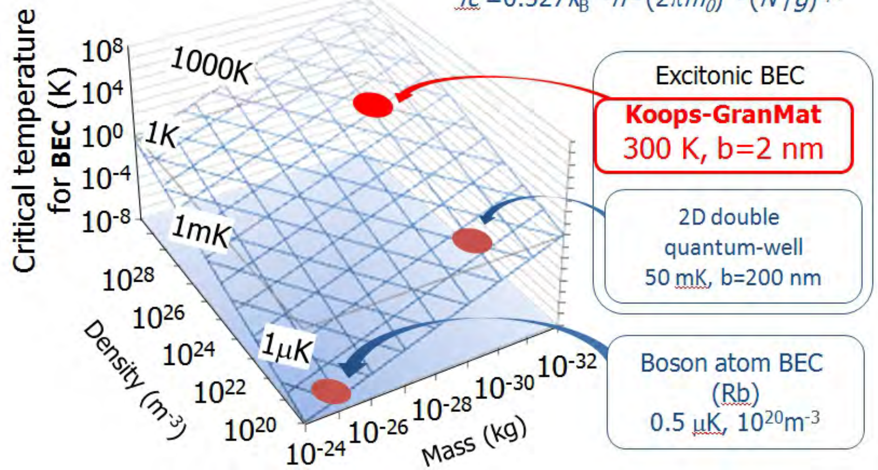
Koops-GranMat®: nanogranular material discovered in 1994 in Pt/C and Au/C

H.W.P. Koops , H Fukuda Conference publication to ICNT2014 submitted to JVSTB-A-14

Quantum Condensation Temperature

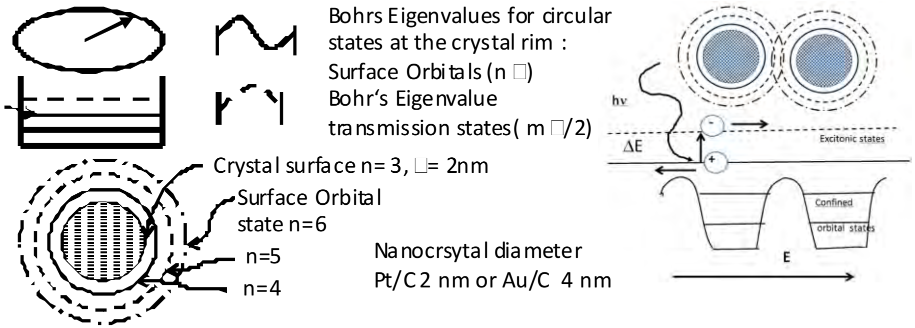
Critical temperature for BEC is calculated: **Room Temperature** because of high density and small mass of electron

$Tc = 0.527 k_B^{-1} h^2 (2\pi m_0)^{-1} (N/g)^{2/3}$



Overlapping electron states allow the formation of a Bose-Einstein Condensate, Using 1 common energy state throughout the material in which Bosons are coherent like in a LASER
Electrons (-,↑) and holes (+,↑) combine to a Boson: (Charge 0, 2 magnetons, strong dipole moment), and leave the Fermi-Dirac statistics (only 2 electrons per energy state), to form Bosons following Maxwell statistics and allowing unlimited number of now coherent Bosons in the state

Molecular surface orbital computation, can handle today ca. 300 atoms, but not >1000 per crystal , nor the interaction of > 3000 metal atoms with an intermediate carbon phase. Therefore a semiclassical approach is the application of Bohr's atom model .

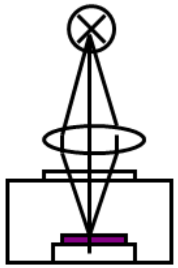


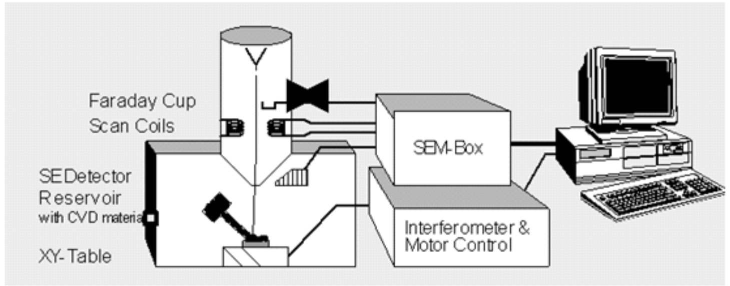
Energy-induced local reactions with 3-D- Nano-Printers

Photons
(Laser)
Reaktive Gases in Environmental chamber
Strukturing by stage movement x y z
Photolysis /Thermolysis

Ion beams
RIE/ single beam
Reaktive Gases in Environmental chamber
Strukturing by Beam motion x y t

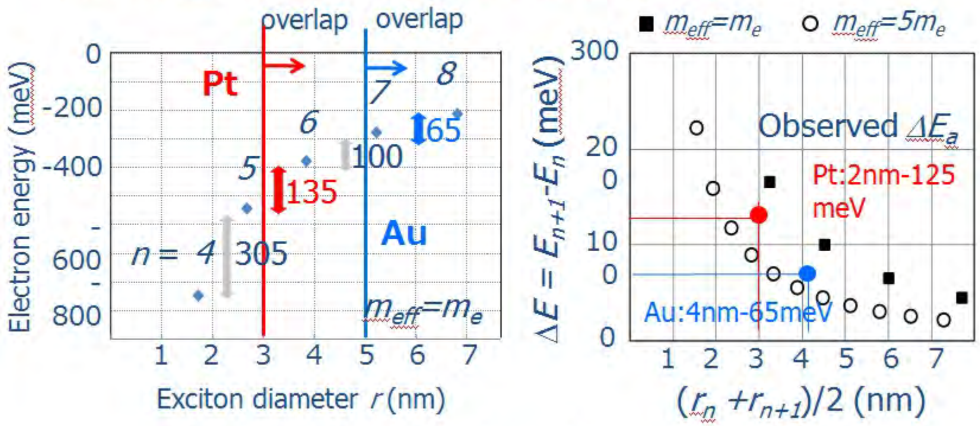
Electron beams
single beam/ Projection
Reaktive Gases in Environmental chamber
Strukturing by Beam motion x y t
Mask





Excitonic states are approximated with Bohr's model

Predicted ΔE between confined and overlapping orbit agree with the observed ΔEa- activation energy for electron hopping



Bohr's model

Bohr radius: $r = \varepsilon n^2 h^2 / (\pi m_{eff} e^2)$ **Energy level** $E = -\, m_{eff} e^4 / (8\varepsilon^2 n^2 h^2)$

Koops-GranMat®

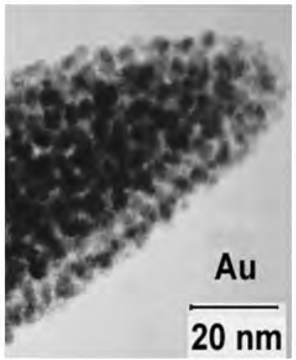
Metal crystals in a Fullerene matrix

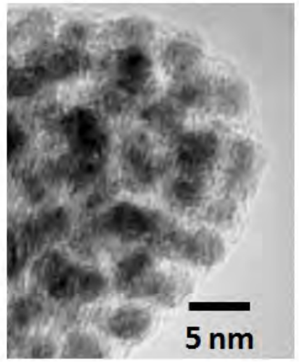
Growth-rate: 1 µm / min @ 100 Monolayers / sec, 0.5 nA 20 kV, spot 2 nm

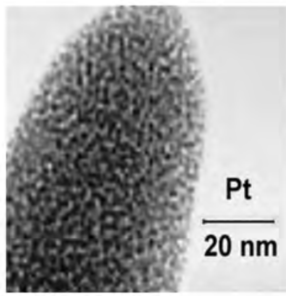
Dimethyl-Gold-Trifluoro-Acetyl-acetonate
Crystal size Au: 3-4 nm

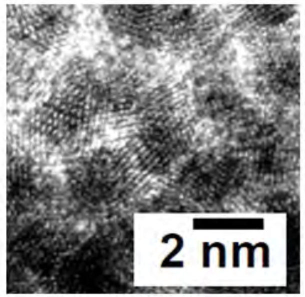
Cyclopentadienyl-Platinum-Trimethyl
Crystal size Pt: 1,8-2,1 nm

Koops-GranMat® materials aggregate by fractioned epitaxy during deposition with crystals showing no percolation.

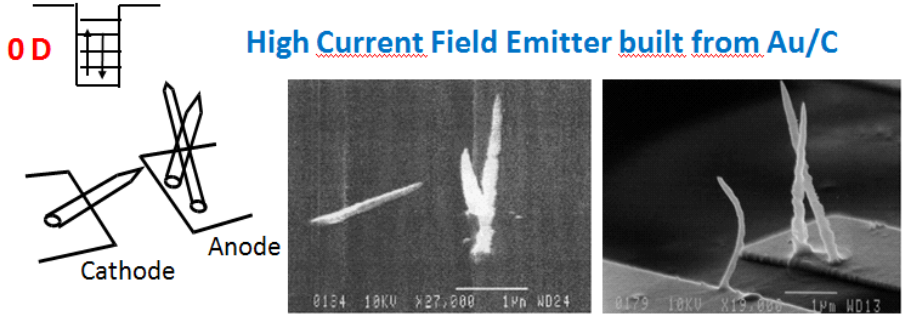




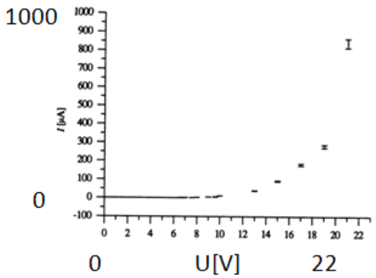




High Current Field Emitter built from Au/C



Field emitter diode   Current bends wire by ion implantation



I/U Characteristics of field emitter experiment

Emission current 850 µA for minutes

Rod diameter 100 nm

j = 10,8 MA/cm² in wire

At tip : 10 nm diameter: **j = 1,08 GA/cm²**

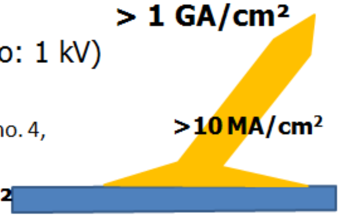
From 1 crystal, 4 nm dia. : j = 6,75 GA/cm²

J. Kretz et al.
ME 23 (1994) 477-481.

Significant features of Koops-GranMat®

(1) Negative temperature dependence of resistivity
(2) Photocurrent response – 3 x more efficient at 700 nm than Si solar cell in white
(3) High current carrying capacity (>10 MA/cm² current density, wires (50 nm),
(4) High contact resistance due to hopping + tunnelling (< 0.01 Ohmcm)
(5) No heat damage (despite (3) and (4)),
(6) Low emission voltage. (Au/C: 22 V, Pt/C: 70 V, Mo: 1 kV)
(7) Coherent electron emission from field emitter tip

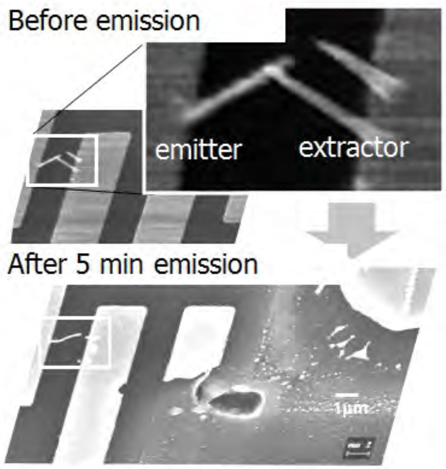
([] K. Murakami, F. Wakaya, M. Takai, J. Vac. Sci. Technol. B, vol. 25, no. 4, pp. 1310-1314, 2007)



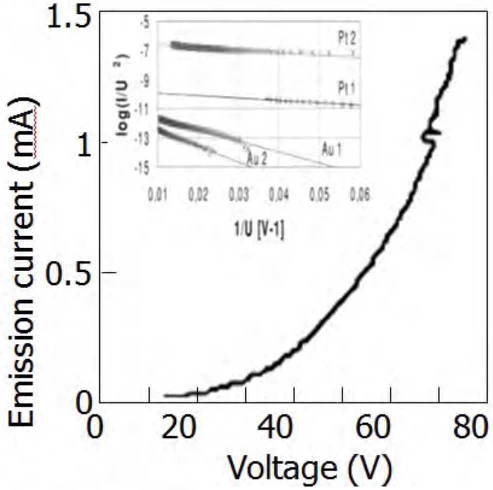
It is a contradiction, that
Gold: resistance. 1 µOhmcm, carries Current: < 250 kA/cm²
and NGM: Contact resistance 0.01 Ohmcm carries > 50 MA/cm² on 70 nm dia wire. The high current density in **KGM** can be supplied by Gold only via a large area contact from Gold to **KGM**, **which must be provided.**

Like for Copper(2,5 KA/cm²) to Superconductors (<1 MA/cm²)

Giant emission current obtained in vacuum electronics device made from Koops-GranMat®. FN-plot shows field emission



E-beam impact melts Gold and Si O_2

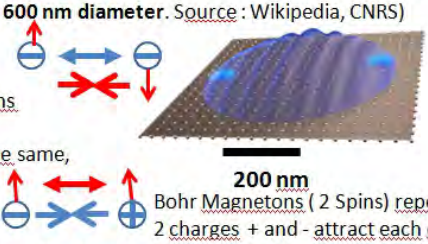


F. Floreani et al. Microelectronic Engineering 57–58 1009 (2001)

Superconductivity is explained by the creation of a **quantum collective wave**, **the condensate** is formed by a large number of electrons. The "Pauli exclusion principle" only allows the existence of such a condensate if the waves which compose it are carried by particles called **Bosons.** Unfortunately, electrons and holes are Fermions, not Bosons.
One energy state can be occupied by 2 electrons with opposite spin (Fermi-Dirac Statistics).
Leon Cooper [of Bardeen, Cooper and Schrieffer] discovered the solution to this problem, showing that in order to form a condensate, electrons must form pairs first.
Indeed, a pair of electrons, a Cooper pair can form a Boson (Maxwell statistics)
In conventional superconductors, the creation of electron pairs and the formation of the condensate happens instantaneously.
2 Electrons repell each other
2 Bohr Magnetons (Spin) attract e.o.
Charge: 2e, Spin: 1 – 1 = 0. **The dimension is up to 600 nm diameter**. Source : Wikipedia, CNRS)

Bose Einstein Condensate

It is predicted by Bose, that in BEC the same happens but with reversed charge and spin role.
However the laws for repulsion or attraction stay the same, just the sign changes.
The sizes remain the same for BCS or BEC Bosons.



Bohr Magnetons (2 Spins) repell
2 charges + and - attract each other

Such a Boson, however, has a strong dipole moment. The extraction voltage forms an electrostatic field with a strong gradient. Dipole moment times field gradient represents a force on the dipole. This moves the Boson until one part feels the field gradient, and then the Boson decays, and releases the electron. Since Bosons move without friction inside the Koops-GranMat® a huge current is flowing, as experimentally measured: 1 mA per emitter, at > 3 GA/cm² current density at the tip.