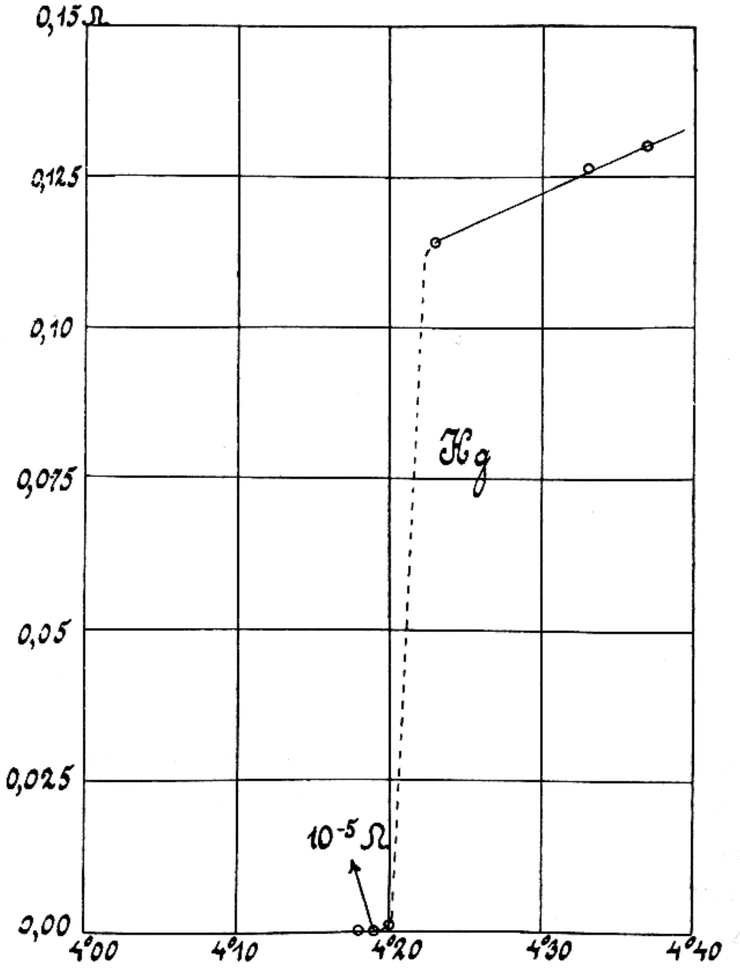
Introduction to superconductivity

Superconductivity

Discovered on 1911 by Heike Kamerlingh Onnes , who was studying the resistance of solid mercury at cryogenic temperatures using the recently-discovered liquid helium as a refrigerant .

Zero resistance

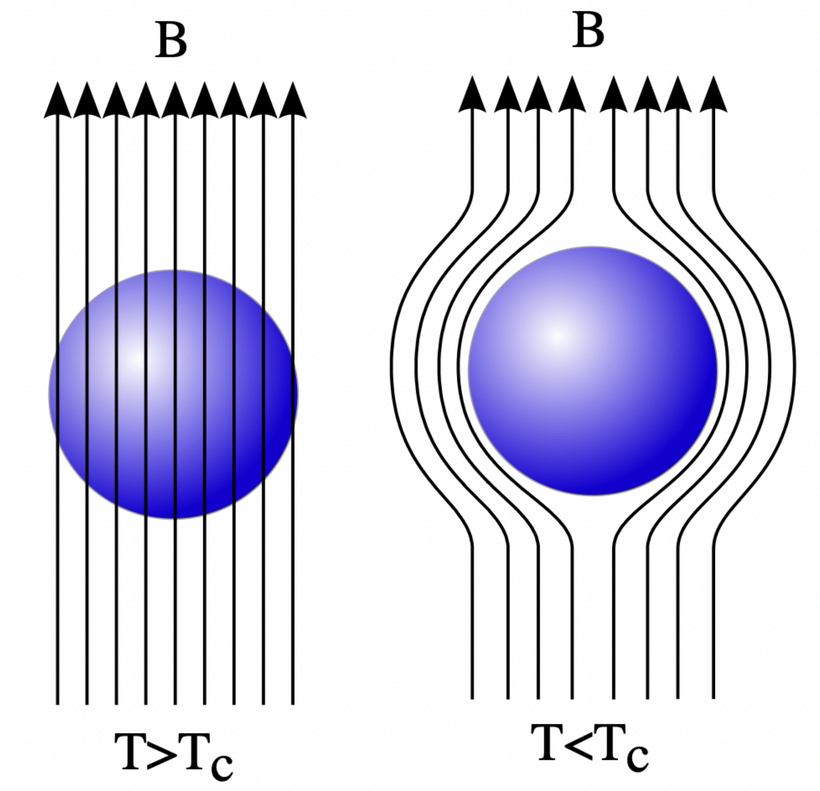



Heike Kamerlingh Onnes
(1853-1926)

H. K. Onnes, Comm. Leiden, 124c, 1911

Superconductivity

Meisner effect



Normal state Superconducting state

By Piotr Jaworski, PioM EN DE PL; POLAND/Poznań - Inspiration: Image:EXPULSION.png, Public Domain, https://commons.wikimedia.org/w/index.php?curid=325237

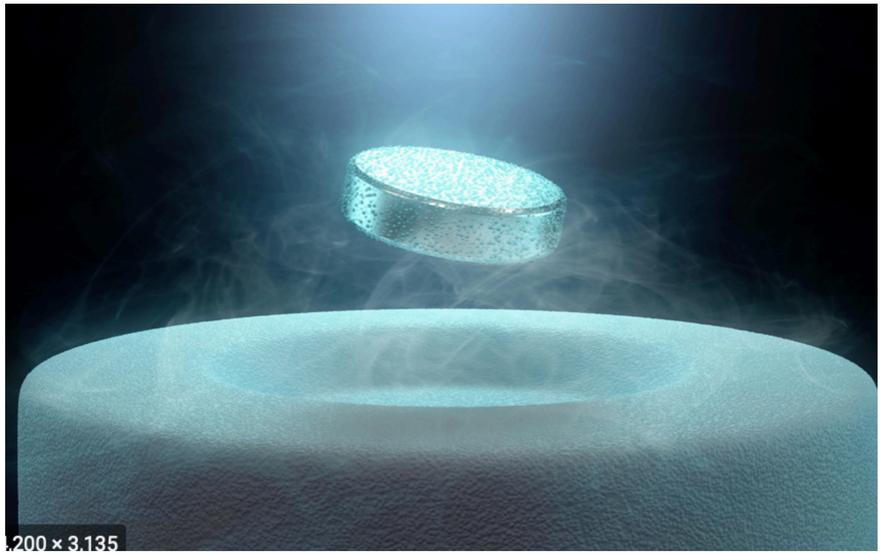
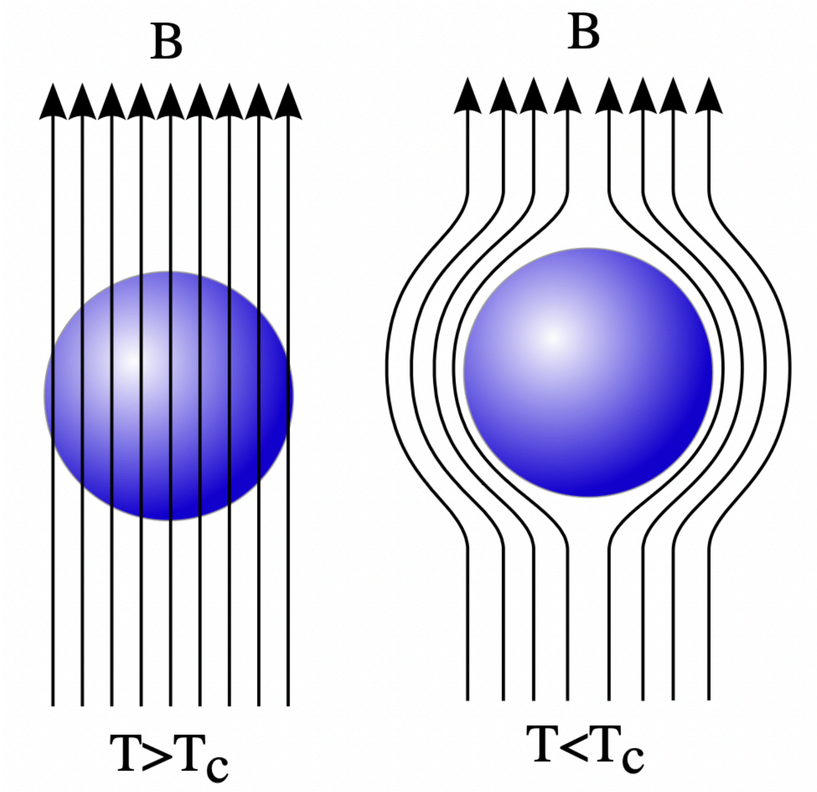


Image from https://www.scientificamerican.com

Superconductivity

Meisner effect



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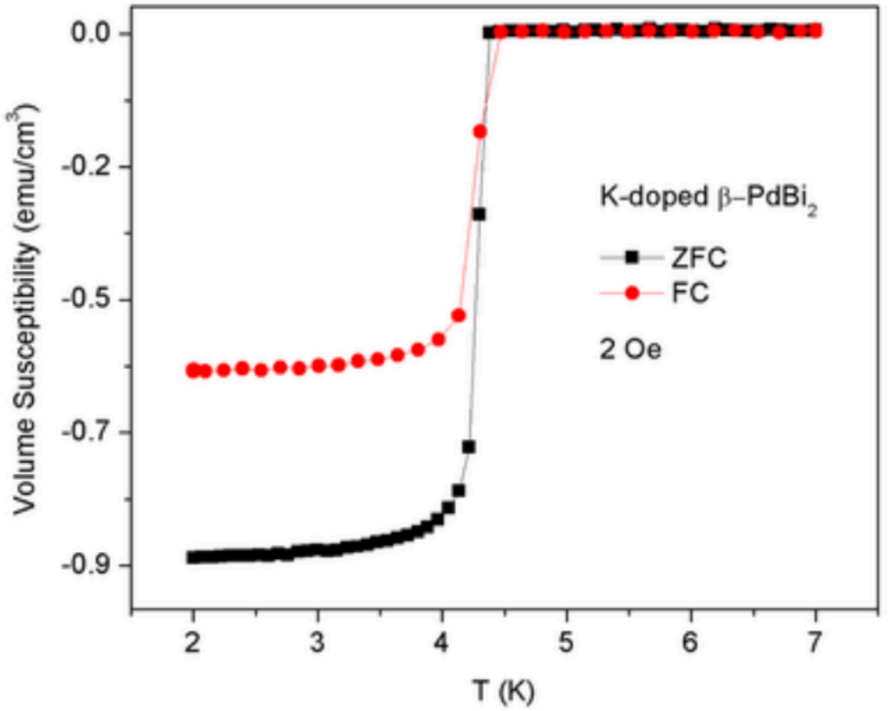
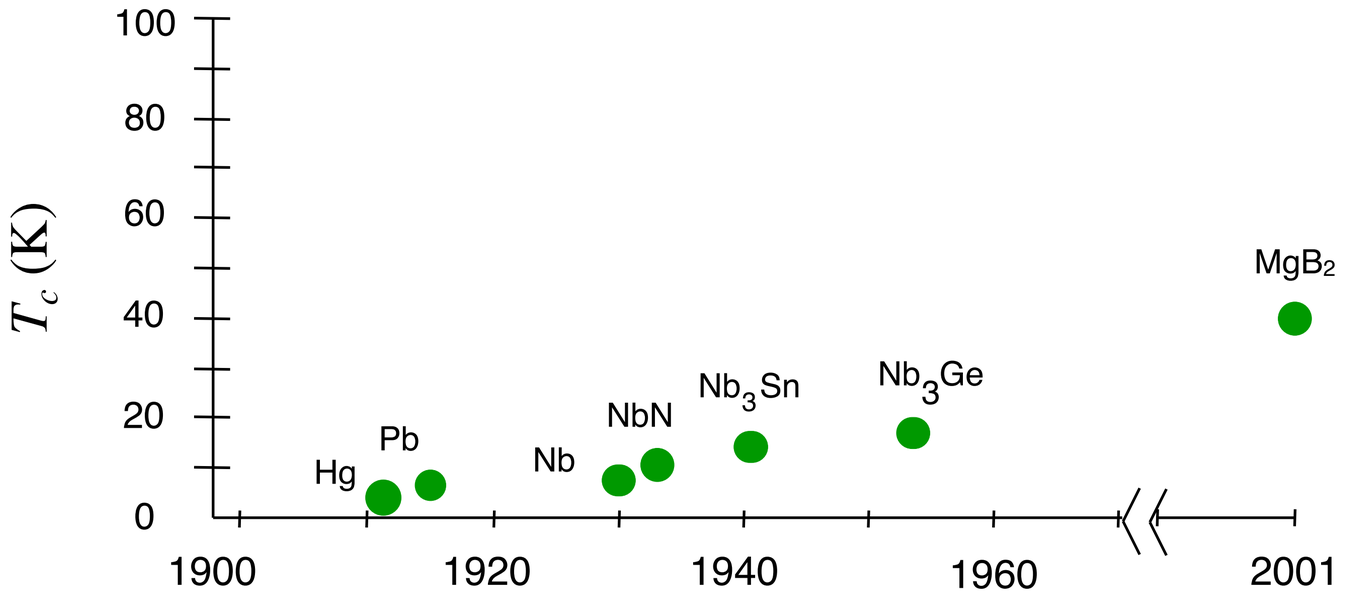


Perfect diamagnetism

Magnetic susceptibility $\chi = -1$

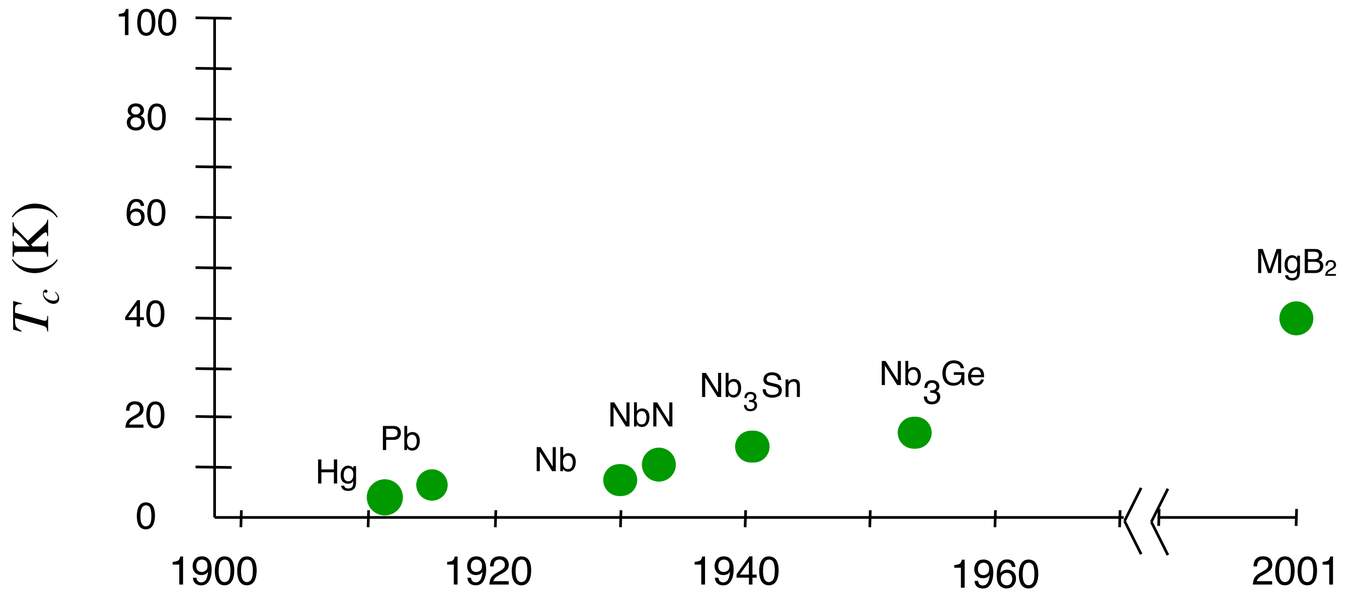
Superconducting Materials Synthesis Timeline



Conventional or Low-T_c superconductors:

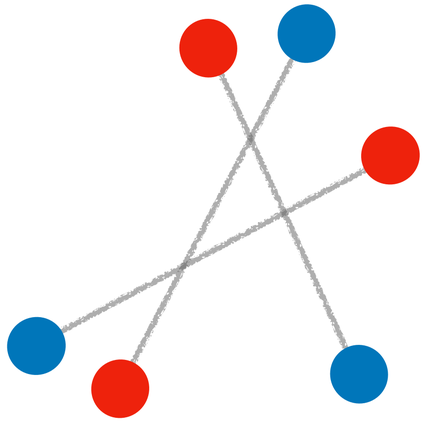
- discovered 1911
- almost all metals (Hg, Pb, Nb, etc.), especially poor ones.
- theory well understood (BCS)

Superconducting Materials Synthesis Timeline



Distance between two electrons

$\xi \gg 10$ nm



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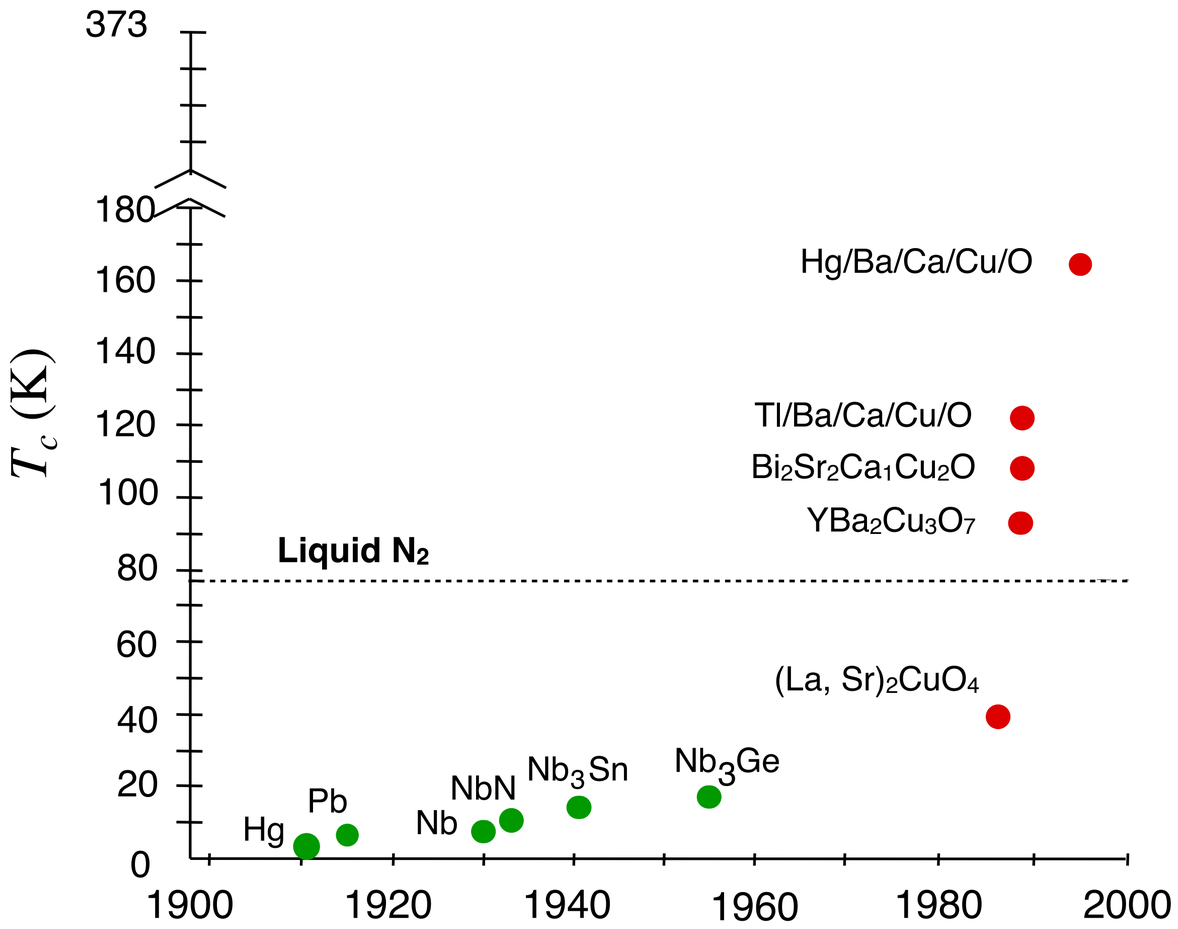
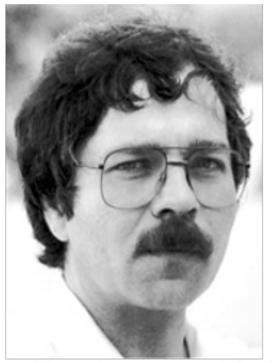
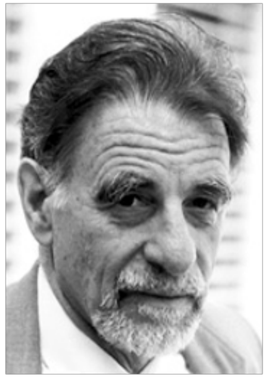




J.G. Bednorz Nobel 1987



K.A. Müller Nobel 1987

High temperature superconductor **cuprate**:

- discovered 1986
- Copper oxygen planes
- theory not understood

Cuprate High T_C Superconductor

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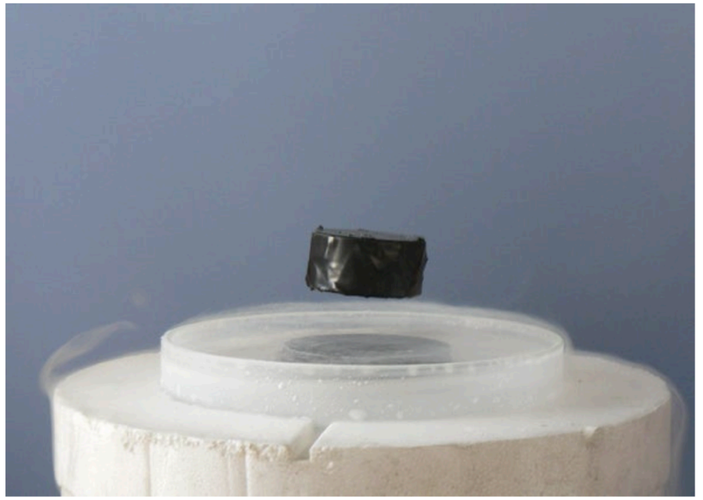
我国自主研制速度可达600km/h的高温超导电动悬浮交通系统实现首次悬浮运行



Credit: Mai-Linh Doan/ Wikimedia Commons, CC BY-SA 3.0

Cuprate High T_C Superconductor

“Above, Long Island Power Authority (LIPA) is utilizing a cable system manufactured by Nexans that utilizes AMSC’s HTS wire and an Air Liquide cooling system. Energized in April of 2008, this is the world’s first superconductor transmission-voltage cable system and is capable of transmitting up to 574 megawatts (MW) of electricity and powering 300,000 homes.”

From: https://blog.advancedenergyunited.org/this-is-advanced-energy-high-temperature-superconducting-transmission

Cuprate High T_C Superconductor cable

Tape

- Superior in-field critical current and excellent mechanical properties applicable for magnet applications
- Original key manufacturing techniques of IBAD & PLD process enabling high superconducting performance

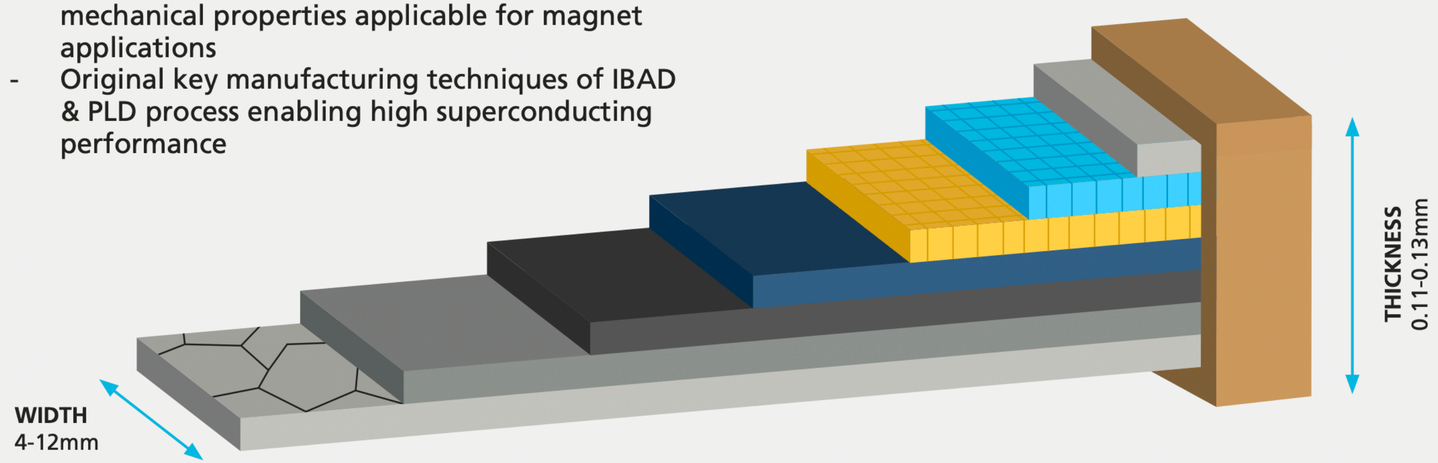


Image from: https://www.fujikura.co.uk/products/fel2ghts_high-temperature-superconductors

Cuprate High T_c Superconductor wire

Cable

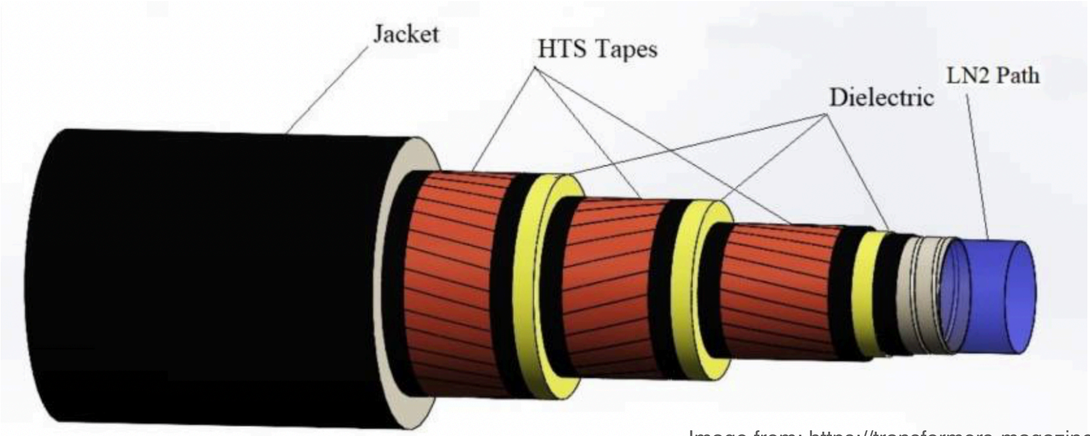


Image from: https://transformers-magazine.com/magazine/an-accurate-model-of-the-high-temperature-superconducting-cable-by-using-stochastic-methods/

Tape

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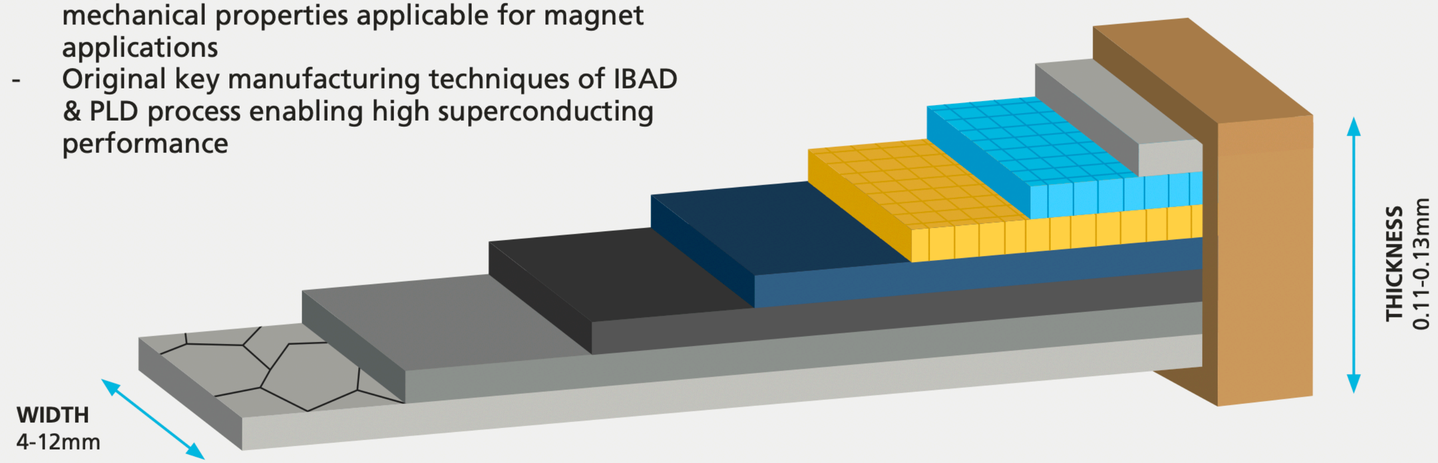


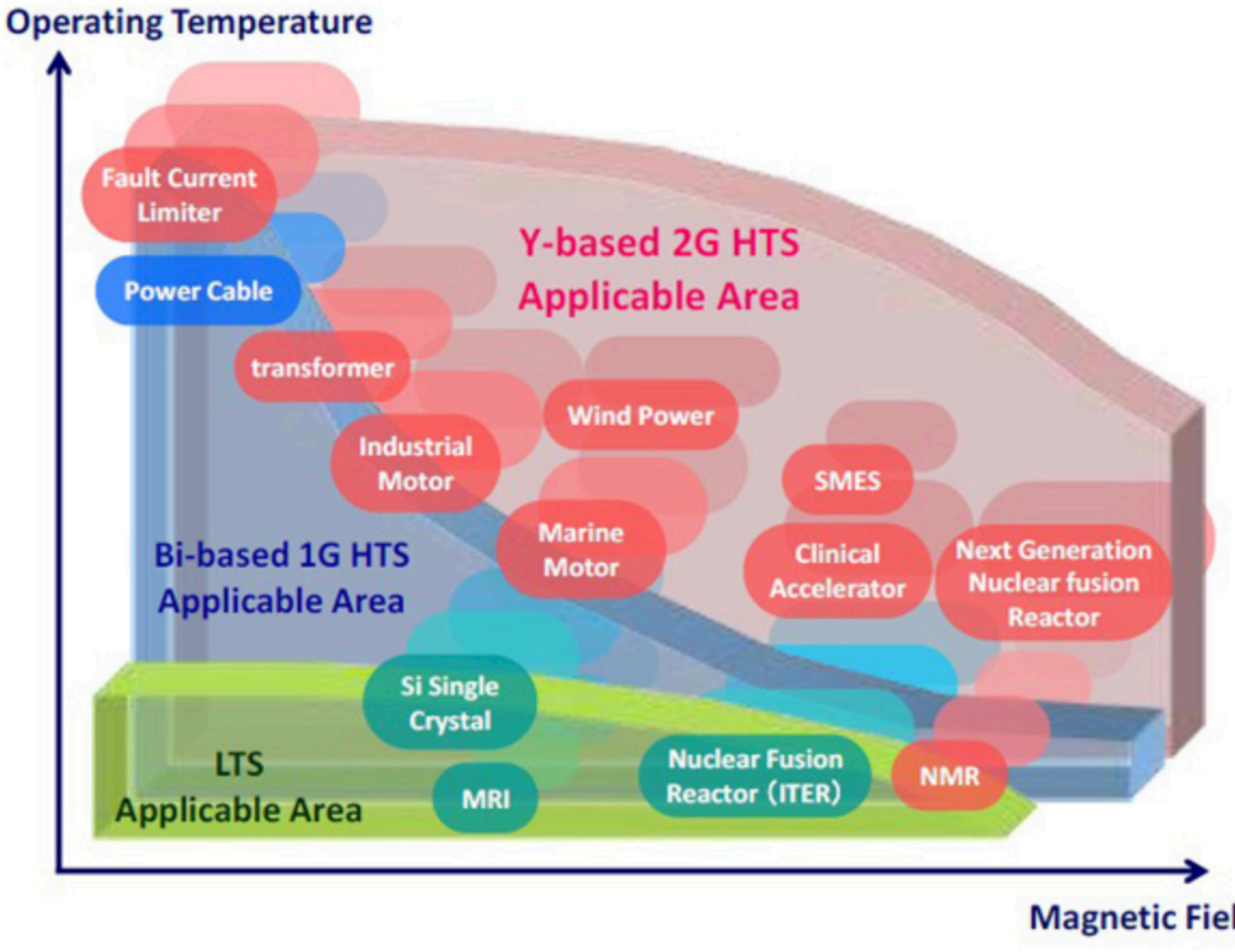
Image from: https://www.fujikura.co.uk/products/fel2ghts_high-temperature-superconductors

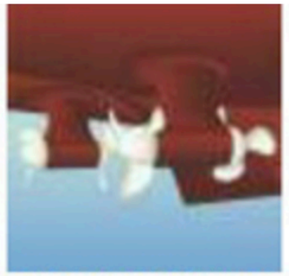
Cuprate High T_C Superconductor

Power Cable

Transformer

FCL





Marine Motor

Wind Power

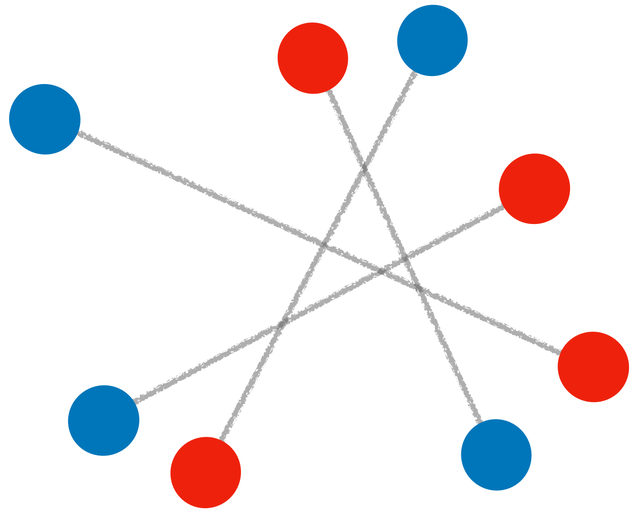
NMR

Image from https://www.fujikura.com/solutions/superconductingwire/

Superfluidity

- Electron pairs condensed into superfluid (BCS condensate)
- Dissipation-less (i.e. no friction / zero viscosity)

Superfluid of electron pairs
(BCS condensate)



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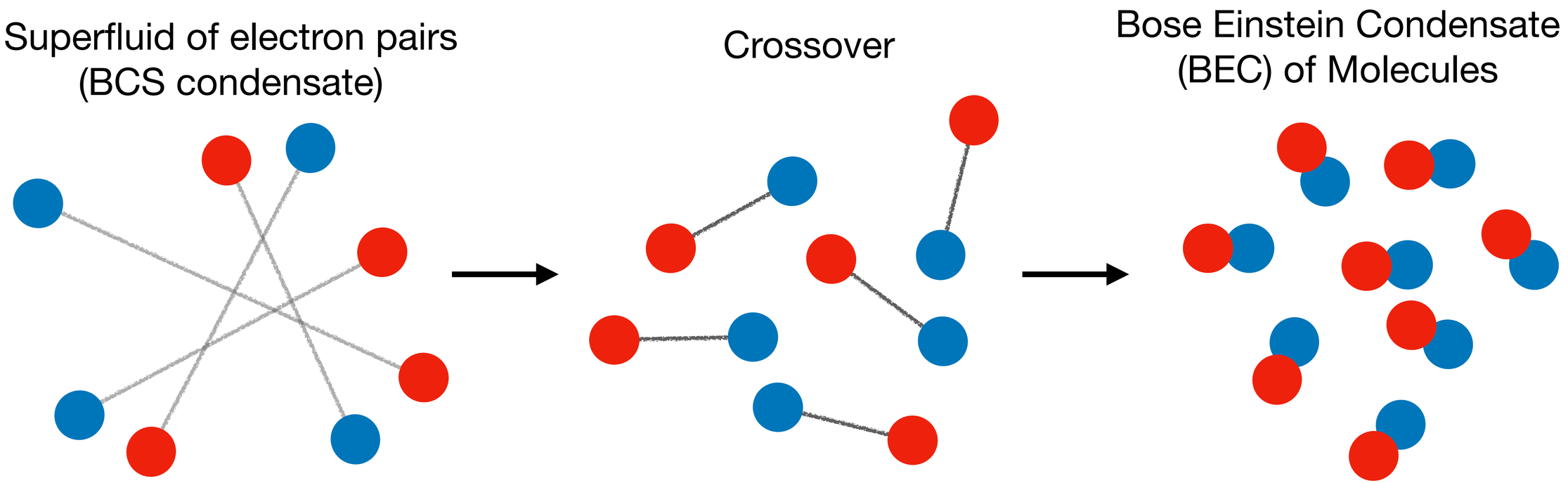


Superfluidity

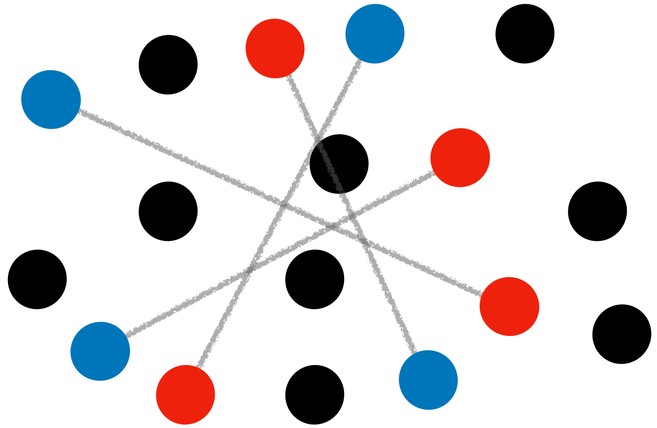
- A macroscopic quantum state that can be described by a macroscopic wave-function

- The absolute value of the macroscopic wave-function is defined by the superfluid density

$$|\Psi|^2 = |\rho_s|$$

$$\Psi = \sqrt{\rho_s} e^{i\theta}$$

Superfluid of electron pairs
(BCS condensate)



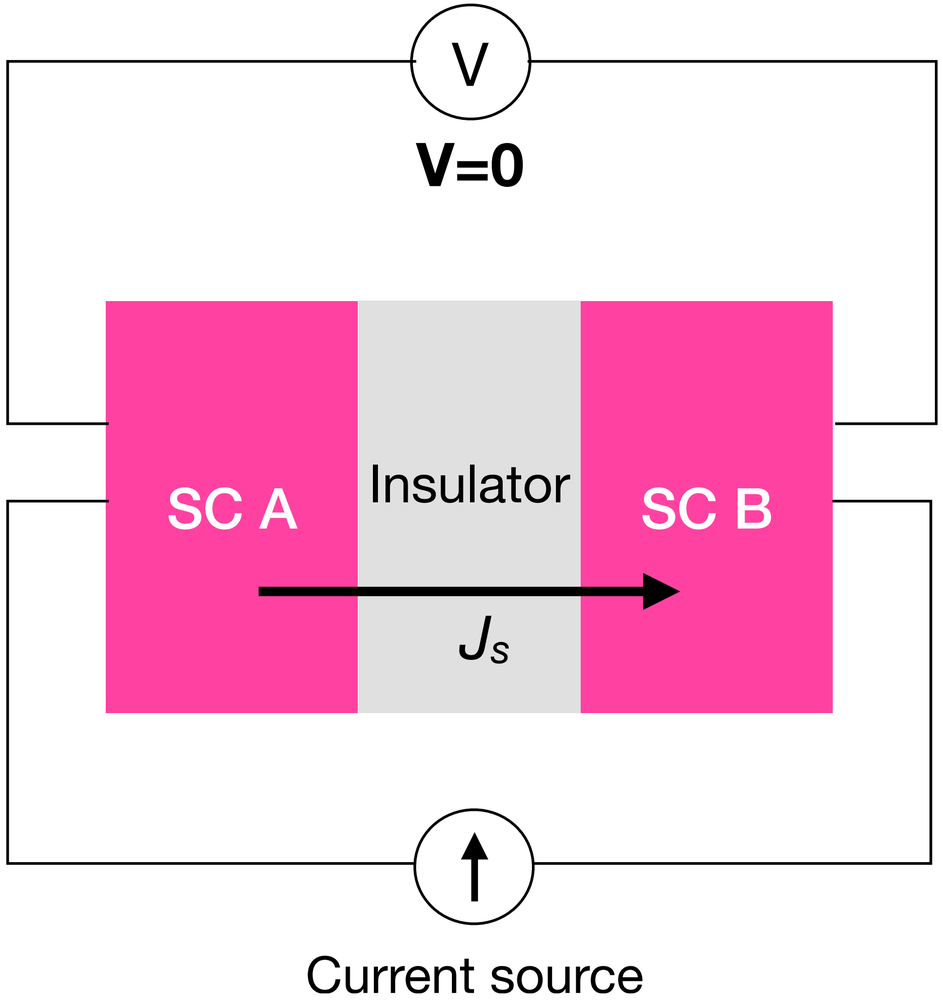
$$\frac{\rho_s}{\rho_N} \ll 1$$

Josephson effect

—DC Josephson effect

DC Josephson effect: $J_S = J_0 \sin(\theta_B - \theta_A)$

A supercurrent J_s flows through the junction without any voltage applied



Josephson effect

— Applications

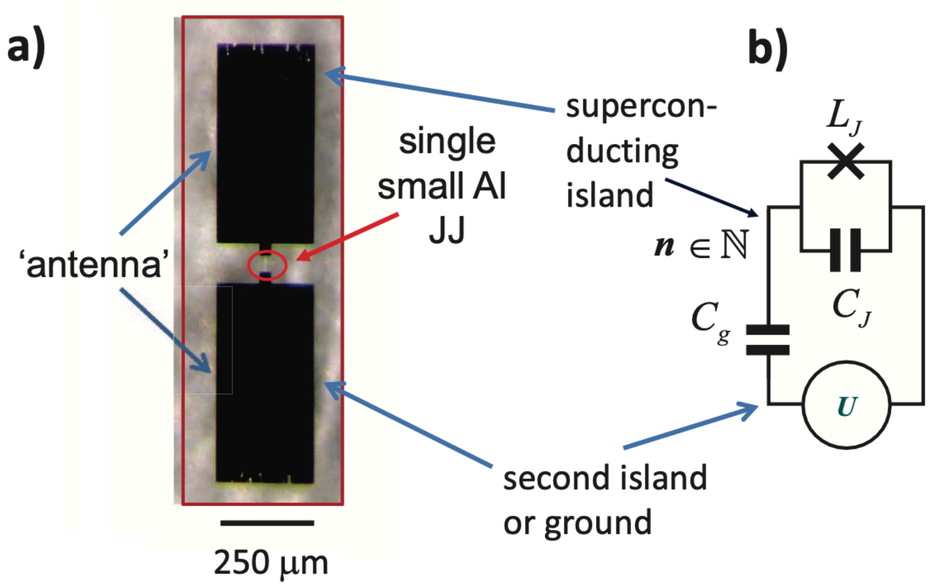
Magnetic field sensor (SQUID)

Superconducting Qubit

Electronic metrology

….

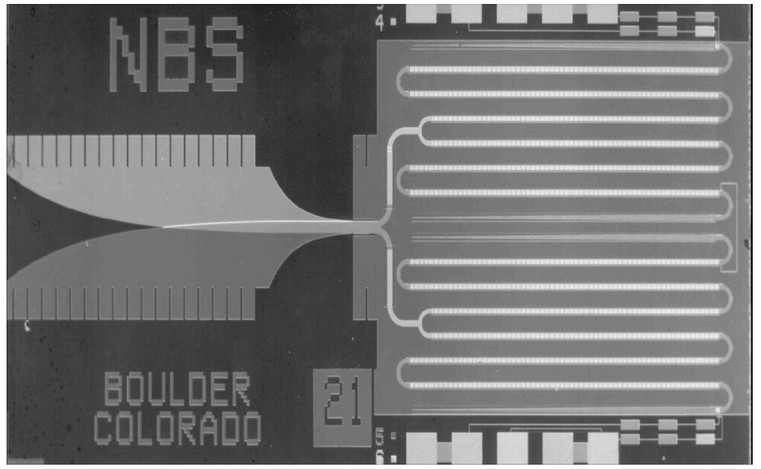
A transmon SC Qubit



Check out Girvin's lecture note on circuit QED

https://drive.google.com/file/d/1-6v8nW6xavPOWB4wIYgkQuYSREKMdvDl/view

The NIST "one volt"



By NBS - NIST paper A Practical Josephson Voltage Standard at One Volt, Figure 1, Public Domain, https://commons.wikimedia.org/w/index.php?curid=319467