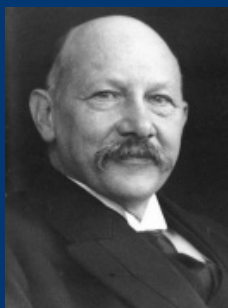


ILC NEWSLINE SPECIAL ISSUE

Happy 100th Anniversary, Superconductivity

This year marks the centenary of the discovery of superconductivity, the property that allows us to focus bunches and bend beams, opening the way to probe the most basic principles of the universe. Without it, there would be little talk of accelerating gradients, quality factors or large colliders. In this issue, we celebrate the weird and fascinating phenomenon discovered 100 years ago.

AROUND THE WORLD

Impersonating bulk niobium

Jefferson Laboratory scientists ionise niobium to make thin films that may outperform their bulkier sibling.

by Leah Hesla



Anything bulk niobium can do, thin films can do better. At least, that's the hope of Jefferson Laboratory scientists, who are currently exploring a method that would allow them to create customisable thin niobium films.

DIRECTOR'S CORNER

One hundred years of superconductivity

by Barry Barish



This year is the 100th anniversary of the discovery of superconductivity in 1911, the central technology employed in modern particle accelerators.

FEATURE

from *CERN Courier*: Inside Story: The discovery of superconductivity

The discovery of superconductivity



One hundred years ago, on 8 April 1911, Heike Kamerlingh Onnes and his staff at the Leiden Cryogenic Laboratory were the first to observe superconductivity. In a frozen mercury wire, contained in seven U-shaped capillaries in series,

electrical resistance suddenly seemed to vanish at 4.16 K.

AROUND THE WORLD

from *DESY inForm*: No resistance

Superconductivity discovered a hundred years ago



These are the electrifying moments to make a scientist's life worth living: take up work at a laboratory, carry out measurement series and, suddenly, see absolutely unexpected results – a tiny detail which is wrong. The measurements are repeated and tested for possible mistakes – but the unexpected proves true.

SUPERCONDUCTIVITY - USEFUL RESOURCES



Superconductivity primers

Learn all about superconductivity and its applications with these helpful online resources.

[Celebrating 100 years of Superconductivity](#)

To celebrate 100 years of superconductivity, IOP Publishing has made 100 articles available free to read for the duration of 2011

[La supraconductivité dans tous ses états](#)

Un site interactif sur la supraconductivité

[Superconductivity in all its forms](#)

An interactive site on superconductivity

[NIST Online Museum of Quantum Voltage Standards](#)

A history of quantum voltage standards by the US National Institute of Standards and Technology



Superconductivity in the media

All over the world news outlets reflect on the remarkable achievements made possible by the discovery of Heike Kamerlingh Onnes on 8 April 1911.

from *BBC*

18 April 2011

[Superconductors got hot 25 years ago](#)

Superconductivity is a hundred years old this month, and a way to make it accessible turned 25 this week. But just how it does what it does remains a mystery even now.

from *Scientific American*

8 April 2011

[Absolute Hero: Heike Onnes's Discovery of Superconductors Turns 100 \[Slide Show\]](#)

A century after the discovery of materials that conduct electricity without resistance, the applications remain disappointingly limited. That may be about to change.

from *Science*

8 April 2011

[Superconductivity's Smorgasbord of Insights: A Movable Feast](#)

On 8 April 1911, physicist Heike Kamerlingh Onnes scrawled in a notebook misdated 1910, "Mercury practically zero." Lost in a page of text, that cryptic phrase marks perhaps the most important discovery in the physics of materials.

Superconductivity in *ILC* *NewsLine*

Look back on superconducting technology's contribution to the International Linear Collider and particle physics in back issues of *ILC NewsLine*.

22 April 2010

[Superconducting cavities could help reducing nuclear waste radio-toxicity](#)

28 January 2010

[Successful beginning of S1 global at KEK](#)

26 February 2009

[Past successes in superconducting RF are a good omen for the ILC](#)

6 December 2007

[ILC challenges materials science](#)

22 June 2005

[Superconducting RF – a technological basis for the ILC](#)

from *physicsworld.com*

6 April 2011

[Down the path of least resistance](#)

Since its discovery 100 years ago, our understanding of superconductivity has developed in a far from smooth fashion.

from *Nature*

1 April 2011

[A very cool birthday](#)

Superconductivity may have reached its centenary, but if anything it's a more active field of research today than ever. From materials dull or shiny, to the race for the Higgs boson, superconductivity remains relevant and exciting.

VIDEO OF THE WEEK



LHC superconducting magnets

CERN's video on superconducting magnets takes you from the pure physics of superconductivity to its application in particle colliders. See the Meissner effect in action and learn about how superconducting magnets were designed and installed in the Large Hadron Collider.

[View the video](#)

IN THE NEWS

from ***New Scientist***

03 May 2011

[Fleeting antimatter trapped for a quarter of an hour](#)

The team working on the Antihydrogen Laser Physics Apparatus (ALPHA) at the CERN particle physics laboratory near Geneva, Switzerland, have stored atoms of antihydrogen for 1000 seconds – roughly 10,000 times longer than before.

from ***Fermilab Today***

2 May 2011

[First beam to MuCool Test Area](#)

A decade ago, a muon collider was considered nearly impossible. Now, scientists at Fermilab's MuCool Test Area are a step closer to testing some critical components for such an accelerator.

CALENDAR

UPCOMING EVENTS

[Linear Collider Power Distribution and Pulsing workshop](#)
LAL, Orsay, France
09- 10 May 2011

[ILD Workshop 2011](#)
Orsay, France
23- 25 May 2011

[Second Workshop on linac operation with long bunch trains](#)
DESY, Hamburg, Germany
06- 08 June 2011

[Technology and Instrumentation in Particle Physics 2011 \(TIPP 2011\)](#)
Chicago, IL
09- 14 June 2011

UPCOMING SCHOOLS

[École IN2P3 - Pays Méditerranéens des Accélérateurs de Particules](#)
Gammarth-Tunis, Tunisia
09- 14 May 2011

[USPAS sponsored by Stony Brook University](#)
Melville, New York
13- 24 June 2011

[View complete calendar](#)

PREPRINTS

ARXIV PREPRINTS

[1105.0511](#)
CALICE Report to the DESY Physics Research Committee,
April 2011

[1104.5389](#)
Anomaly Puzzle, Curved-Spacetime Spinor Hamiltonian, and
String Phenomenology

[1104.5316](#)
Anomalous single production of fourth generation t' quarks at
ILC and CLIC

[1104.5132](#)
Measuring the top Yukawa coupling at the ILC at $\sqrt{s} = 500$ GeV

AROUND THE WORLD

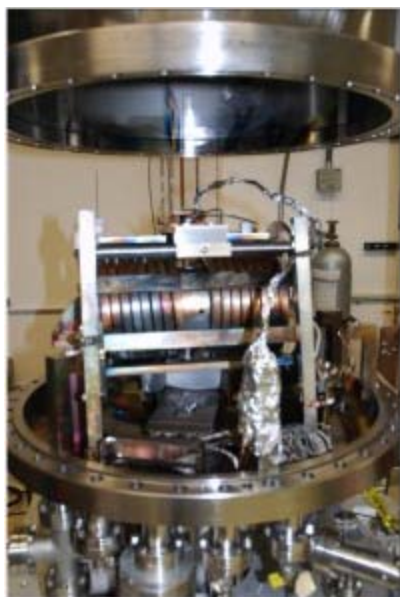
Impersonating bulk niobium

Jefferson Laboratory scientists ionise niobium to make thin films that may outperform their bulkier sibling.

Leah Hesla | 5 May 2011

Superconducting radiofrequency power only runs skin-deep, and accelerator scientists have been taking advantage of the phenomenon's surface-crawling tendencies with a view to making high-performing, low-cost accelerator cavities. The trick is to manipulate a metal's top-most layer so that it conducts just like a thick slab of superconducting material.

Scientists at Jefferson Laboratory in the US are researching a deposition technique for applying thin niobium films to a metal's surface. The approach, layer deposition via electron cyclotron resonance (ECR), allows them to fashion fine layers into something that could be mistaken for the tried-and-true superconductor standby, bulk niobium.



Vacuum chamber for energetic condensation via electron cyclotron resonance. The vacuum chamber is open to show the coil structure in the center. Niobium atoms are ionised inside the coil by electrons. The substrate on which the ions are deposited is positioned at one end of the coil. Image courtesy of Anne-Marie Valente-Feliciano.

"The top layers should effectively mimic bulk niobium performance," said Anne-Marie Valente-Feliciano, scientist in the Process and Materials Group at JLab's SRF Institute.

If the layers do a good job of it, expensive niobium cavities could be dispensed with altogether. Lower-cost copper or aluminium cavities with niobium thin films could replace them.

"Using niobium layers is a way to produce the lowest-cost accelerating structures you can possibly make," said JLab SRF scientist Larry Phillips who, along with Ron Sundelin and Genfa Wu (now at Argonne National Laboratory), broached the possibility of pursuing ECR for cavities at JLab in the late 1990s. Recent funding has kicked the current effort into high gear.

The crucial, cost-saving act of mimicking bulk niobium depends on the layers' atomic structure. Superconducting electrons should flow through the layers as they do in bulk niobium – with little interruption from the atoms in the mix. If the electrons' experience is more like a ball in a pinball machine, scattering every which way off atomic obstacles, the thin films have to be deposited differently.

With ECR, scientists can control the layers' deposition in a way that minimises those obstacles and defects.

The method begins with the vaporisation of a solid niobium target in a vacuum chamber. Electrons, accelerated by electric and magnetic fields (oriented perpendicularly to each other), ionise the niobium vapour with an energy of about

64 electronvolts. Now charged, the niobium ions are pulled towards a voltage-biased substrate. They settle on the metal and arrange themselves in a way that's determined by their initial energy and the substrate temperature.

"You can play with the mobility of the ions to achieve certain structures that you wouldn't be able to with other commonly

used methods,” Valente-Feliciano said. For example, with a low-energy deposition method called magnetron sputtering, only a fraction of niobium atoms are ionised. With ECR, on the other hand, scientists can fully ionise the vapour, turning the voltage dial on the substrate to manoeuvre the niobium ions’ landing pattern.

The optimal atomic layer structures are those that minimise the so-called defect density, or the opportunity for electron scattering. Conveniently, the nature of ECR already gives scientists a head start on that front.

With ECR, no carrier gas is used – niobium ions are deposited in an environment that’s evacuated to about 2×10^{-8} torr – so there’s little chance that the system contributes impurities to the substrate. And since electric fields, rather than gases, carry the ions, they must obediently follow the perpendicular field lines that lead to the deposition site, so arriving at the metal head-on. That minimises the chances that atomic-sized voids are introduced into the layer.

But to achieve the best possible niobium layer arrangement, scientists must still contend with unavoidable atomic structural mismatches between unlike materials.

“When you grow thin films, you want to arrange them so that the substrate can be forgotten,” Valente said. The better the mismatches are masked, the more distant the reminder of aluminium or copper beneath the film, and the more closely the layers approach the behaviour of bulk niobium.

To that end, scientists at JLab have been experimenting with different substrate materials, crystallographic structures, varying temperatures and energies.

“You have to understand the correlation among radiofrequency performance, film microstructure and the method you use to produce it,” Phillips said.

Their tests have yielded encouraging results. In a series of tests with ECR-deposited niobium layers on a flat sapphire substrate, JLab researchers were able to show that they could tailor the RRR (pronounced ‘triple R’) value, a measure of the conductivity, from 10 to over 450. That wide range, said Valente-Feliciano, is testament to the technique.

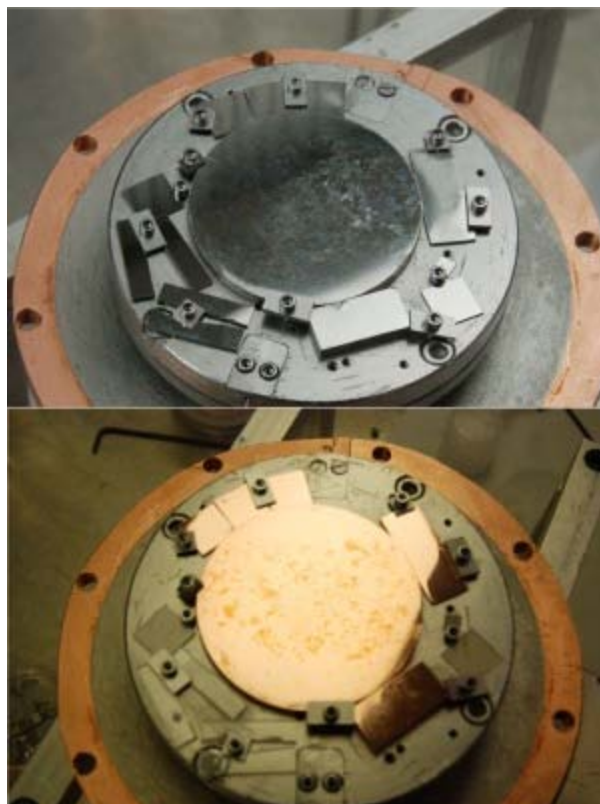
Though thin films’ actual application in cavities is still some years away, JLab scientists intend to push ahead. They’re currently exploring other methods of niobium thin film deposition. They also plan to design a layer deposition system for single-cell cavities, paving the way for further experimentation with accelerator structures.

“Once you’ve reached a limit for bulk niobium, what’s next?” asks Valente-Feliciano. “Thin films are the way to the future. Now is our chance to show what they can do.”

Stay tuned to *ILC NewsLine* for more advances on thin films research. Read about another method of [thin film deposition](#) at Argonne National Laboratory.

[CAVITY PROCESSING](#) | [CAVITY SURFACE](#) | [JEFFERSON LAB](#) | [JLAB](#) | [NIOBIUM](#) | [SUPERCONDUCTING CAVITY](#) | [THIN FILMS](#)

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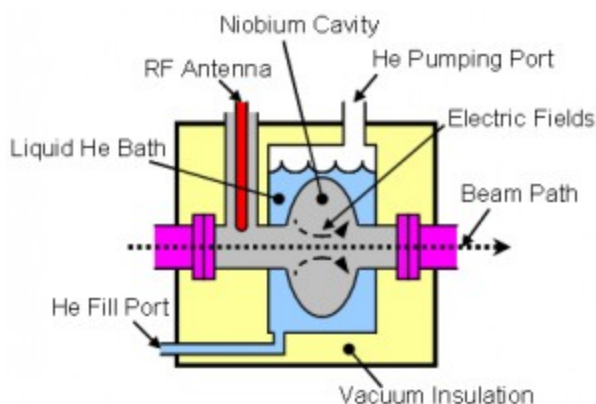


*Samples of ECR-deposited thin films (top) and their substrates (copper, magnesium oxide, sapphire) (bottom).
Image courtesy of Anne-Marie Valente-Feliciano.*

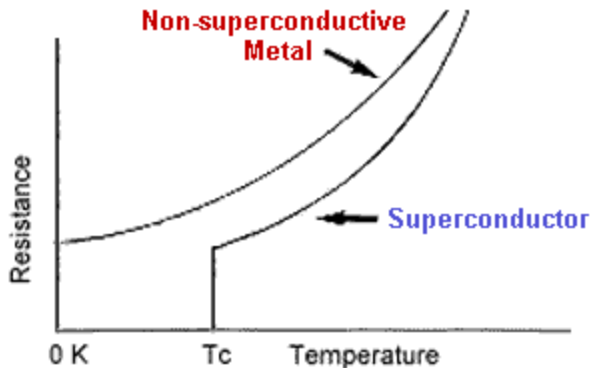
DIRECTOR'S CORNER

One hundred years of superconductivity

Barry Barish | 5 May 2011



A schematic view of a superconducting radiofrequency cavity at liquid helium temperatures.



Onnes observed in 1911 that the resistivity of solid mercury suddenly became zero below 4.19 K.

This year is the 100th anniversary of the discovery of superconductivity, a state in some materials to conduct electricity without energy loss at very low temperatures. Heike Kamerlingh Onnes demonstrated the phenomenon of superconductivity in 1911 at the University of Leiden in the Netherlands when he observed the resistivity of mercury go to zero as he cooled it below 4 kelvin. Onnes won the Nobel Prize in physics for this remarkable discovery, which has had profound impacts on both science and society over the past century. Superconductivity is the central enabling technology employed in modern particle accelerators.

One of the most basic formulas we learn in physics is Ohm's Law, $V = IR$. The voltage drop across a material (e.g., a wire in an electrical circuit) is proportional to the current applied and the resistance of the material. The voltage drop is zero if the resistance is zero, which is a special state for some materials at very low temperatures called superconductivity.

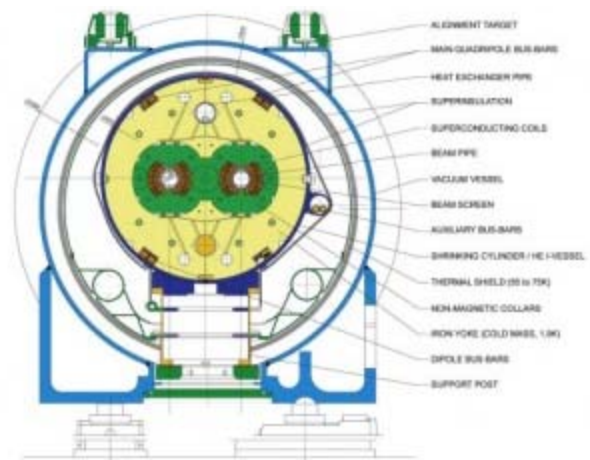
Onnes's research was aimed at understanding how materials behaved as they approached absolute zero temperature. The main question was whether the resistance would go to zero at absolute zero temperature. Resistance was known to be due to the scattering of electrons by ions in the metal, so the question was whether the scattering amplitude decreased to yield zero resistance or whether the mobility of electrons also decreased, giving zero conductivity at zero temperature, which

was Lord Kelvin's hypothesis. In that case, the resistance would reduce to some value, then become infinite at zero temperature.

Onnes first developed liquid hydrogen in 1906, which enabled laboratory studies at 14 kelvin. Although the linear reduction of resistance was observed, the picture was confused by indications of flattening, which might have indicated Kelvin was correct. But the purity of the metal also affected the resistance. Then in 1908, Onnes became the first to develop liquid helium at 4.2 K; it is still the coolant of choice for modern accelerator magnets, magnetic resonance imaging and other applications. In 1911, using liquid helium, he performed the experiments that demonstrated superconductivity and was awarded the Nobel Prize two years later.

Although we almost take it for granted, superconducting magnets are the main enabling technology for modern particle

colliders, bending the particle around the ring. The size of the ring is set by the bending strength, with positively charged particles accelerating in one direction and negatively charged particles sent in the opposite direction. Finally they are brought together to collide at discrete points along the ring. Superconducting magnets generate high fields and use less power than conventional magnets. The LHC has 1,232 superconducting 14.2-metre long dipole magnets with design fields of up to 8.4 tesla distributed around a 27-kilometre circumference ring. The enormous cryogenic system that is required to cool the ring delivers a total refrigeration of 150 kilowatts at 4.5 K and 20 kW at 1.9 K. The experiments also employ gigantic superconducting magnets that create a volume of magnetic field that is filled with sophisticated particle detectors.



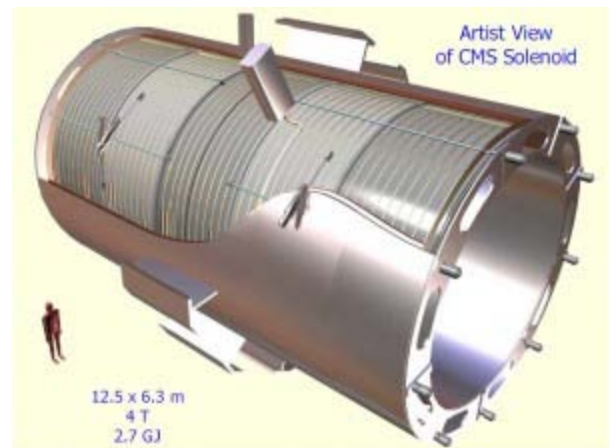
Double-bore magnet configuration of the LHC superconducting magnets.

Particle accelerators and detectors have greatly benefited from the development of superconducting technologies for our applications. We also help drive superconducting technology development and, as a result, have effectively doubled the operating gradients of superconducting magnets over the past couple of decades. For the ILC, our superconducting RF cavity design is based on one-metre nine-cell niobium cavities developed at the DESY. Niobium cavities are limited to gradients of less than 40 to 50 megavolts per metre, and for mass-produced cavities we have set a standard of 35 MV/m, with operational gradient in the machine of 31.5 MV/m. This is again about twice the operating gradient that could be achieved in real applications a decade ago.

SUPERCONDUCTING MAGNET | SUPERCONDUCTIVITY

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The huge superconducting solenoid magnet for the LHC CMS experiment.