The search for CDW depinning in Chromium

Pierre Monceau, Institut Néel, CNRS, Grenoble

A.A. Sinchenko, LPS, University Paris Saclay

PHYSICAL REVIEW VOLUME 128, NUMBER 3 NOVEMBER 1, 1962

Spin Density Waves in an Electron Gas

A. W. OVERHAUSER
Scientific Laboratory, Ford Motor Company, Dearborn, Michigan
(Received June 11, 1962)

The origin of the SDW in chromium, as first understood by Overhauser,[28,29] lies in the pairing of electrons with holes of opposite spin. The pairing is between momentum states separated by **Q**. When **Q** is a vector that "nests" the electron and hole Fermi surfaces, the total electronic energy is lowered and a spiral-density wave results. The ground state is formed from two spiral waves of opposite helicity, resulting in the linearly polarized SDW. For pure chromium, the nesting vector is incommensurate with the lattice and $Q=(1\pm\delta)2\pi/a$ where $a=2.88$ Å. The period of the SDW modulation is ≈ 27 lattice constants at T_N.[30]

Associated with the SDW, a CDW is stabilized with a period twice shorter than the SDW one

Chromium is a body-centered-cubic metal which undergoes a transition at 312 K to a state in which the electrons form a static spin-density wave (SDW) with a period which is incommensurate with the lattice. The magnetized state consists of domains, each containing a single wave with wave vector $\vec{Q}$ along one of the cube axes. In the range of temperature from the Néel temperature 312 K (T_N) to the spin-flip temperature 123 K (T_F), the wave is transversely polarized, with the magnetization pointing along one of the other cube axes. Below 123 K the wave is longitudinally polarized.

The discovery that chromium is antiferromagnetic was made by Shull and Wilkinson[1] in 1953 as a result of a neutron-diffraction experiment. Fur-

Sliding in low-dimensional materials

One dimensional CDW and SDW materials

only a single Q vector

Transition metal dichalcogenides MX_2

Three Q vectors at 120°

Rare-earth tritellurides RTe_3

unidirectional CDW either only on a axis, or both along a and c axis

CDW in three dimensional chromium

CDW Q vector orientated along the a, b, and c axis

Sliding in one-dimensional spin density wave

PHYSICAL REVIEW B VOLUME 41, NUMBER 7 1 MARCH 1990

Phase transition and non-Ohmic electrical transport in the spin-density-wave state of the organic conductor tetramethyltetraselenafulvalinium hexafluorophosphate [(TMTSF)$_2$PF$_6$]

W. Kang, S. Tomić,* J. R. Cooper,* and D. Jérome
Laboratoire de Physique des Solides, Université Paris-Sud, 91405 Orsay, France
(Received 8 September 1989; revised manuscript received 4 December 1989)

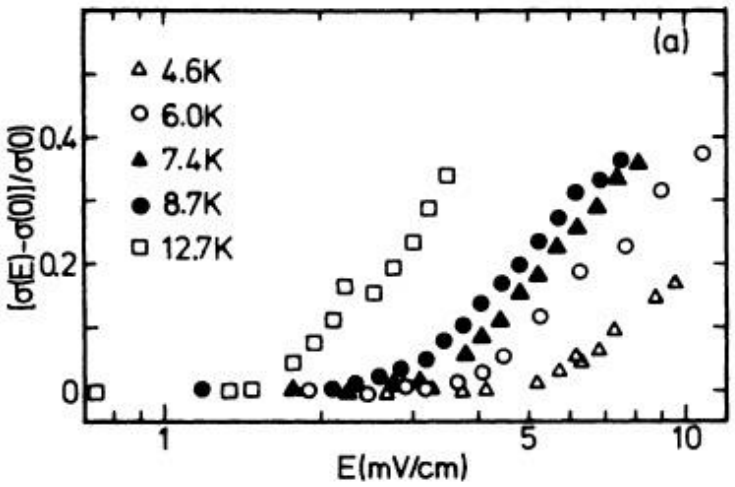


FIG. 2. Non-Ohmic conductivity $[\sigma(E)-\sigma(E\rightarrow 0)]/\sigma(E\rightarrow 0)$ vs the logarithm of electric field (E) at various temperatures of $(TMTSF)_2PF_6$ (a) for sample with clamped con-

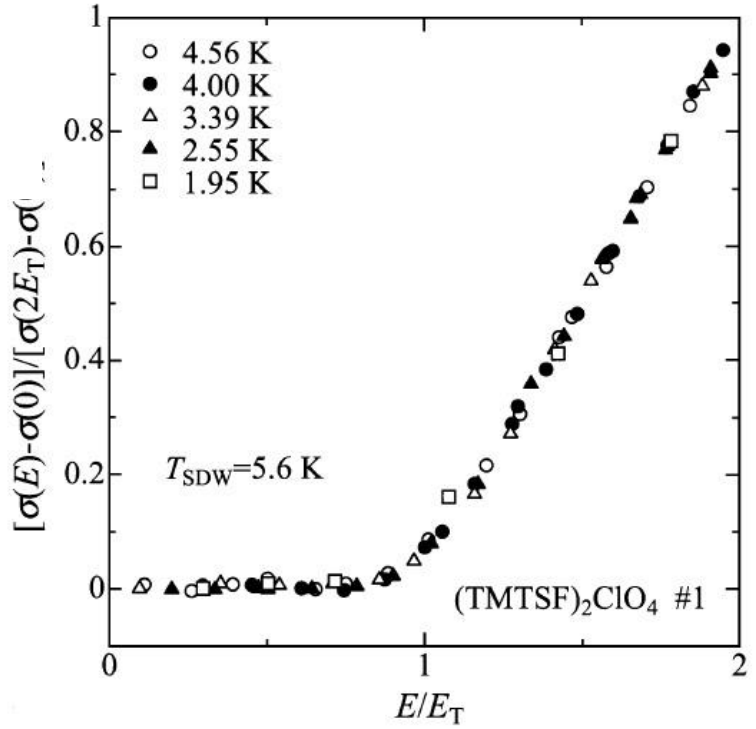


Fig. 4. Electric field dependence of conductivity in the sample #1. The functional form $[\sigma(E)-\sigma(0)]/[\sigma(2E_T)-\sigma(0)]$ is uniform irrespective of the temperature.

A. Hoshikawa et al. J. Phys. Soc. Jpn., 69, 155 (2000)

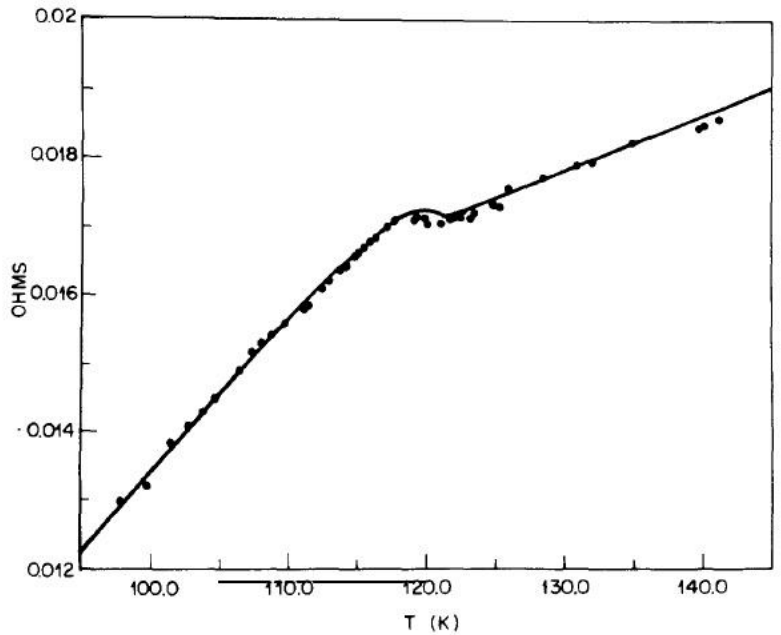
SEARCH FOR A SLIDING CHARGE DENSITY WAVE IN LAYERED COMPOUNDS

F. J. DiSalvo and R. M. Fleming

Bell Telephone Laboratories
Murray Hill, NJ 07974, USA

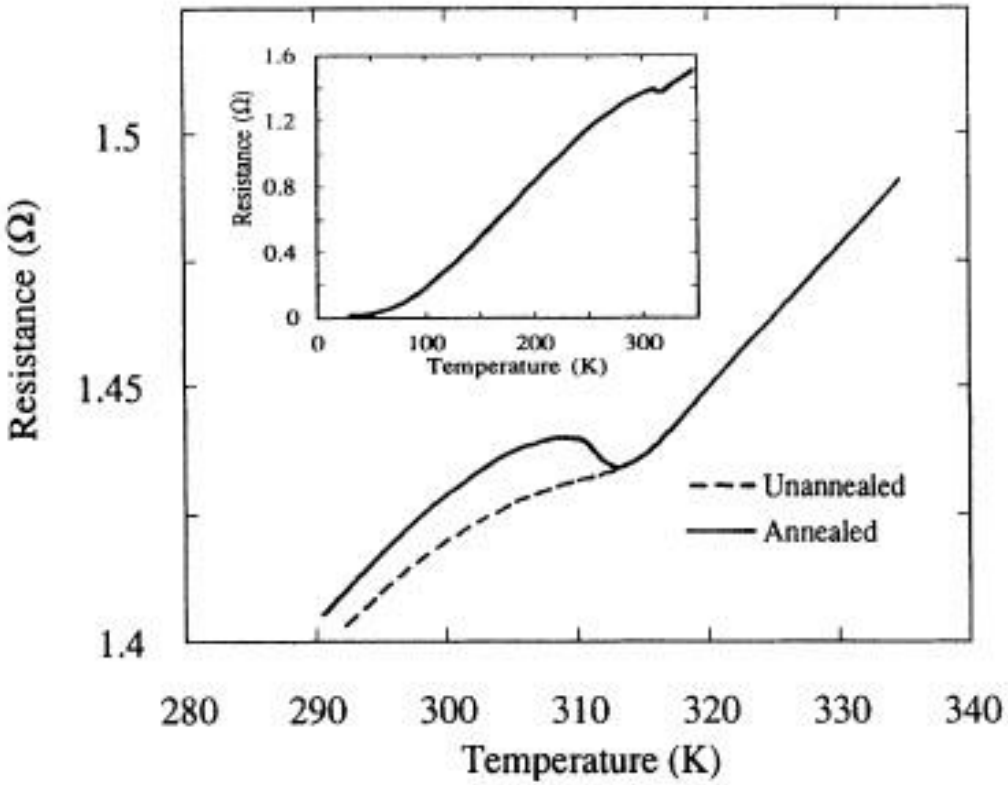
(Received 16 April 1980 by A. G. Chynoweth)

Non-linear voltage-current behavior is observed in the quasi one dimensional compound $NbSe_3$, due to the contribution of a sliding Charge Density Wave (CDW) to the conductivity. We have looked for a non-linear voltage-current characteristic in the incommensurate CDW state of the layered compounds 2H-$TaSe_2$ and 1T-TaS_2 and find no evidence for such up to 1.0V/cm and 10V/cm, respectively. These values are several orders of magnitude higher than the minimum depinning field observed in $NbSe_3$.



The electrical resistance of 2H-$TaSe_2$ with the current flowing parallel to the layers is shown in the temperature range of 95 to 145 K. The solid line is obtained from a low current ac measurement and the points from 30 microsecond high current pulses that produce electric fields in the sample of 1.0 V/cm.

Spin density wave pinning in chromium



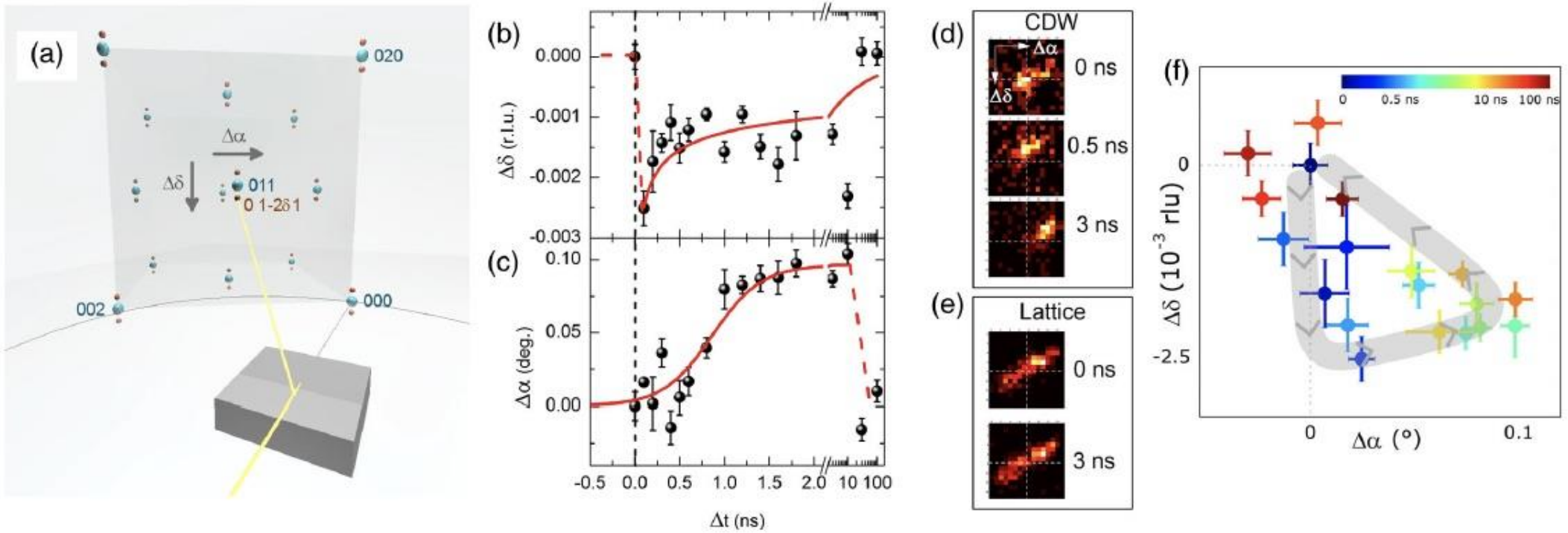
Sample cut with size: 5mm x 0.1mmX 15 microns
Long axe along the 100 axis
Polished
Annealed vacuum 600°C
RRR larger than 200

No nonlinear effects up to 30 V/cm
to be compared to threshold field in 1D: 10mV/cm
or in $TbTe_3$

I.D. Parker and A. Zettl, PRB44, 5313 (1991)

Multi Q structure

Laser-induced CDW transient depinning in chromium



Time-resolved x-ray diffraction measurements following femtosecond laser excitation

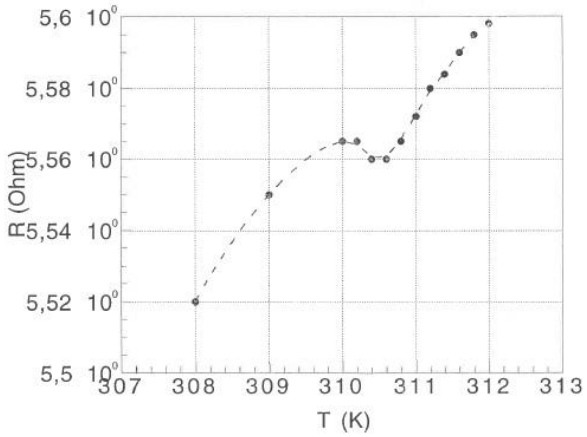
Breaking of the lattice point symmetry

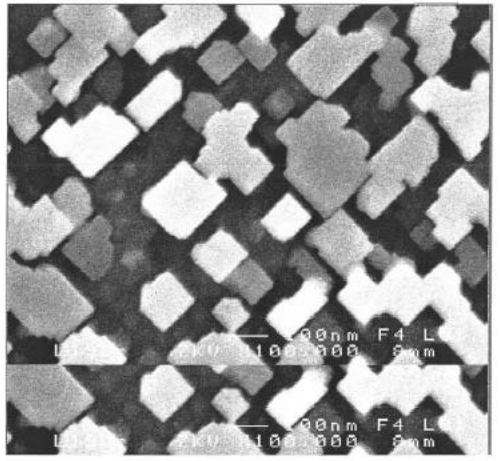
Evolution of the CDW reflexion on the vertical and horizontal directions

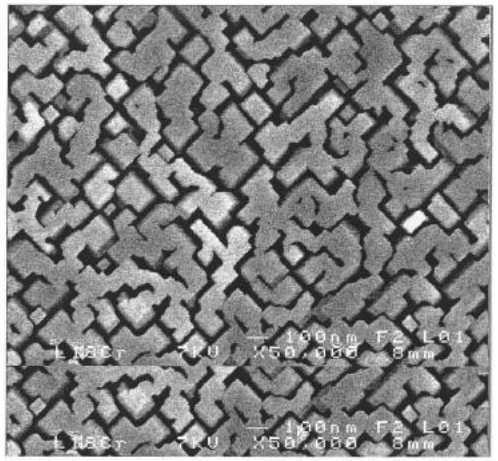
VRL Jacques et al. PRL 117, 156401 (2016)

Chromium thin films

Thin films were grown by laser ablation from pastilles frittées on (100) MgO substrats
They were characrerized in situ by reflection high-energy electron diffraction (RHEED), ex-situ by X-ray diffraction
In the oscillating-crystal mode using a Weisenberg camera and high tresolution scanning microscopy.







The sample was patterned with dimension: L= 555 microns,
l= 183 and thickness: 800nm.

The resitivity of the film just above T_N is 18,3 $\mu\Omega$cm
(12,7 for a single crystal)
The amplitude of the increase of R(T) below T_N is 0,5%
(typically 2,5% in a single crystal
And the RRR were low in the order of 10.

The thin film is well epitaxied, but
polycrystal with domains along the
(100) and (110)
Excess resistance from domain walls

M. Guillou-Vitry et al., University of Rennes,
1996 unpublished

Sliding charge-density-wave transport in micron-sized wires of $Rb_{0.30}MoO_3$

O. C. Mantel, C. A. W. Bal, C. Langezaal, C. Dekker, and H. S. J. van der Zant
Department of Applied Physics and DIMES, Delft University of Technology, Lorentzweg 1, 2628 CJ Delft, The Netherlands
(Received 26 March 1999)

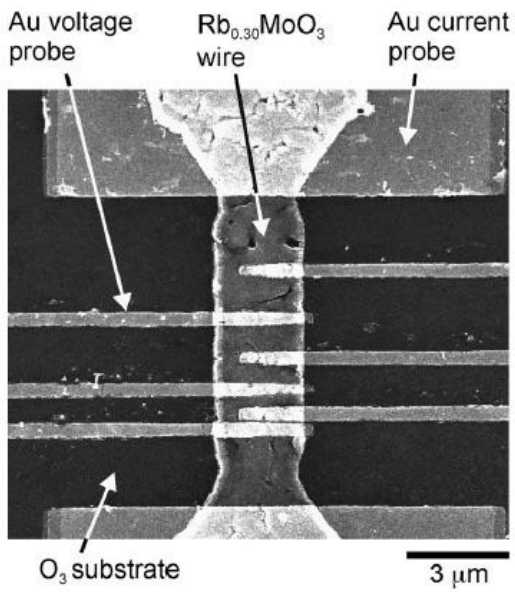


FIG. 1. SEM image of a wire structure patterned into a 0.3-μm thin film of $Rb_{0.30}MoO_3$. Gold current pads and 400-nm-wide voltage probes have been defined on top of the wire by *e*-beam lithography. Distances between middles of the voltage probes, from top to bottom, are 1.5, 1.25, 1.0, 0.75, and 0.5 μm.

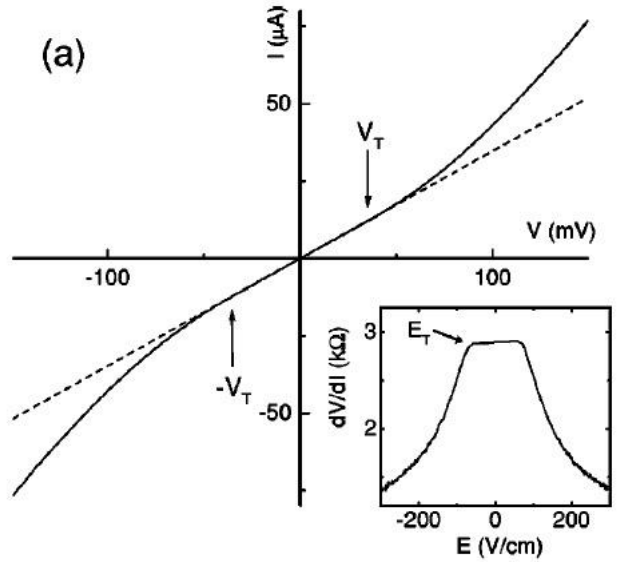


Figure 1 shows a top-view scanning electron microscope (SEM) image of a wire structure. Contacts have been defined by electron-beam lithography. The wire has a width of 2.6 μm and a length between current pads of 10 μm.

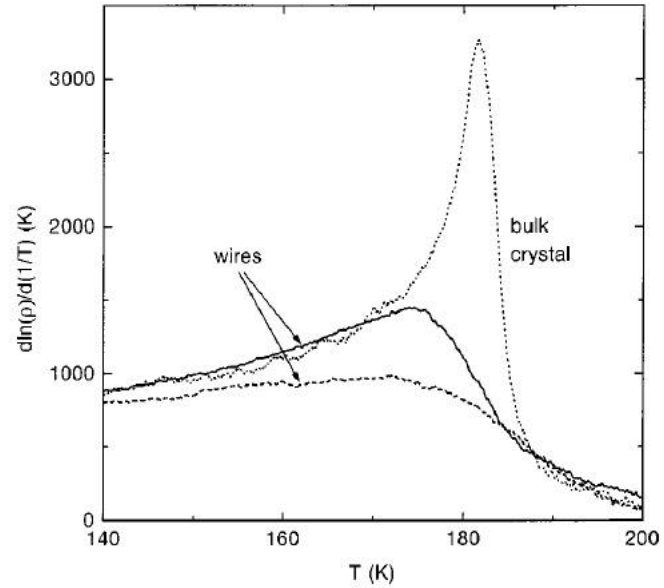


FIG. 3. $d\ln(\rho)/d(1/T)$ vs temperature, demonstrating the Peierls transition for wire 3 (solid line), wire 5 (dashed line), and for a 0.2-mm thick $Rb_{0.30}MoO_3$ crystal with voltage probes 1 mm apart (dotted line). For the wires, a broadening of the transition is observed at a somewhat lower temperature.

Template synthesis of nanomaterials

T.L. Wade[a] and J.-E. Wegrowe

LSI, École Polytechnique, CNRS-UMR 7642 & CEA/DSM/DRECAM, 91128 Palaiseau Cedex, France

Most common templates:
Ion-track etched membranes
Al membranes

(asbestos, porals,…)

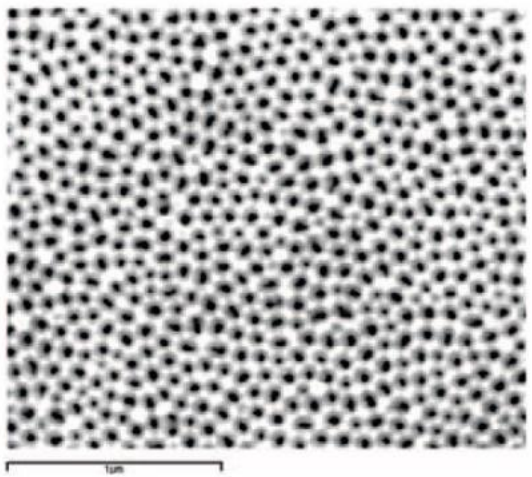


Fig. 5. SEM micrograph of the surface of an alumina membrane made by to-step anodization.

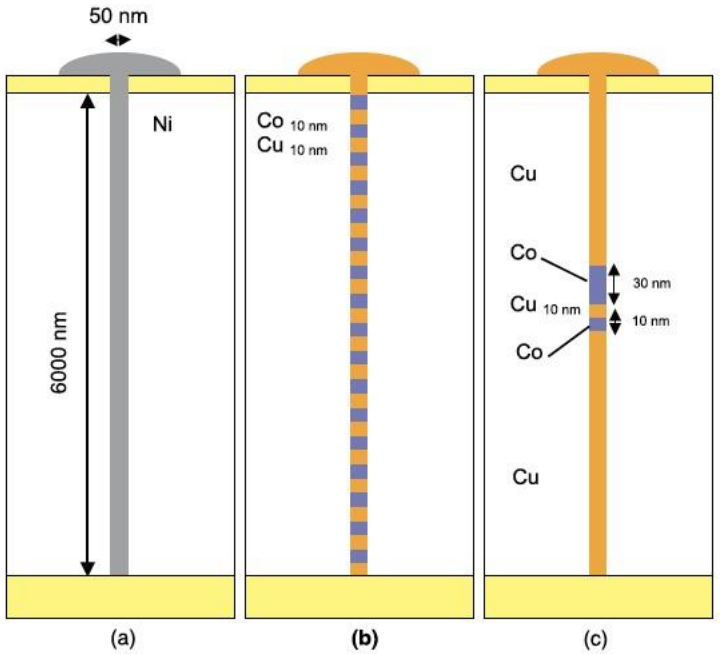


Fig. 7. Three examples of nanowires fabricated in membrane templates.

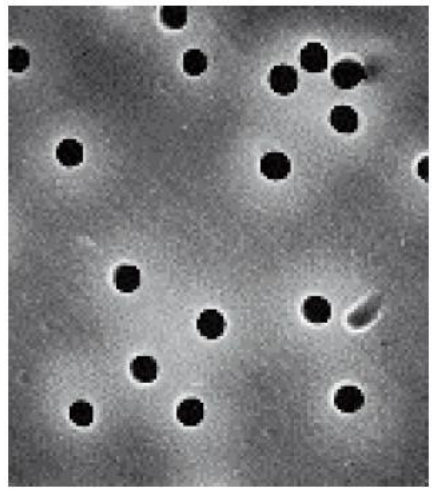


Fig. 3. SEM micrograph of a commercial ion-track etched polycarbonate membrane.

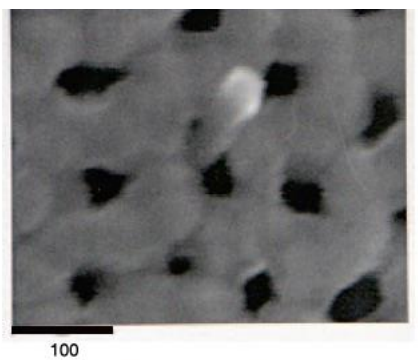
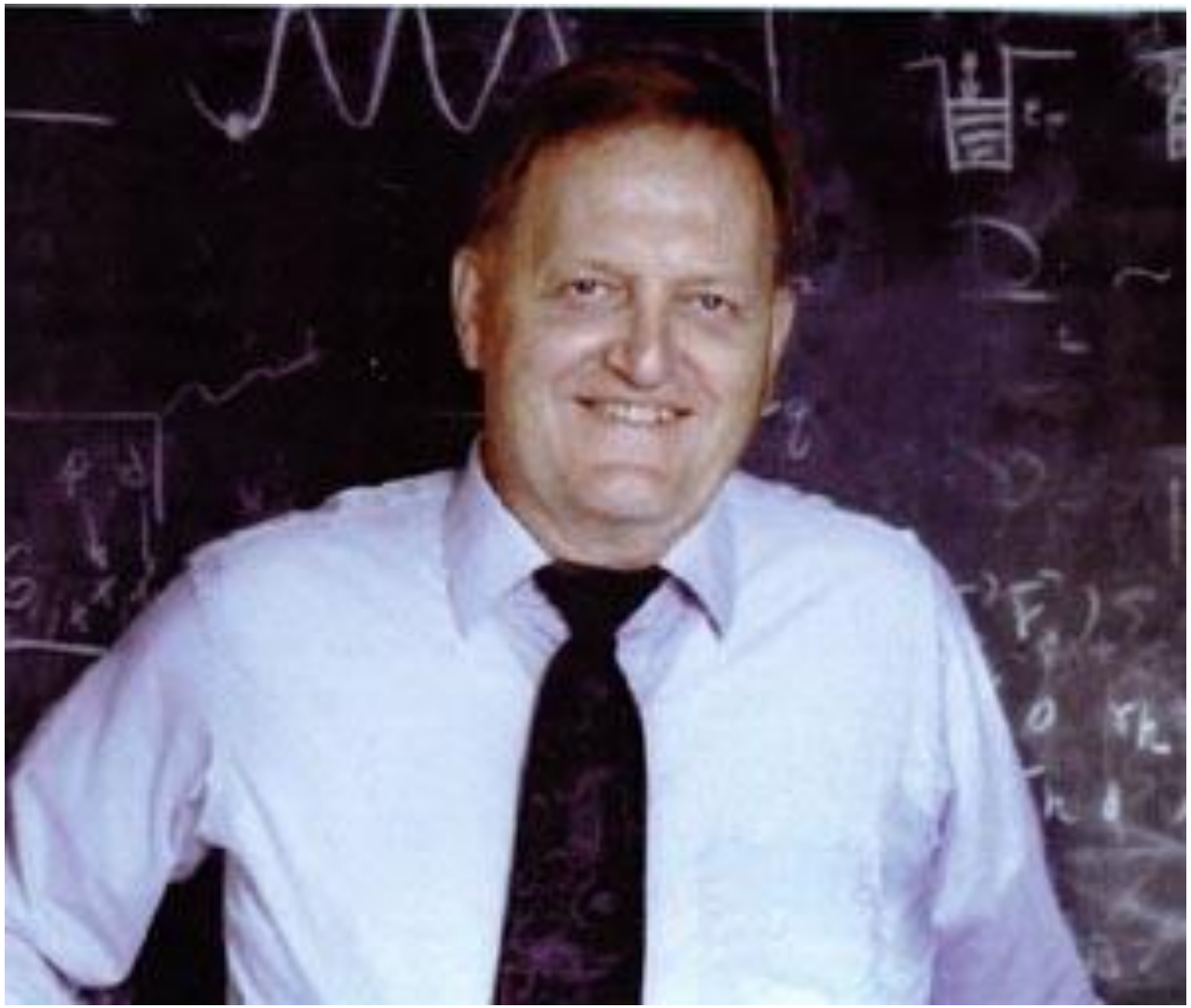


Fig. 19. SEM micrograph of a silicon nanowire exiting from a pore of an alumina membrane.

50nm diameter Nickel nanowire 6000n,m long has a resistance of 260 Ohms

Charge density waves in alkali metals: Potassium



Albert Overhauser
1925-2011

--Overhauser effect

Change of the integrated intensity of the NMR absorption of a nuclear spin in metals when the spin resonance of the electrons is saturated (1953)

the Colella-Overhauser-Werner (COW) effect

Observation of the quantum mechanical phase-shift of neutrons caused by their interaction with the Earth' gravitational field

PRL34, 1472 (1975)

-CDW in alkali metals

The consequences of this discovery---known as the Overhauser Effect---for nuclear magnetic resonance, and through nuclear magnetic resonance for chemistry, biology and high-energy physics have been enormous. The idea, which has also had very practical consequences, was so unexpected that it was originally resisted vehemently by the authorities in the field. Not until its existence was demonstrated experimentally by Slichter and Carver[1] in 1953 was it fully accepted. It has been said that one can judge the importance of a new discovery in physics by the number of other fields of science and engineering it impacts. From this point of view this contribution of Overhauser ranks among the highest.

In simplest terms, Overhauser was the first to demonstrate that it is possible to line-up, or to polarize, nuclear spins by a factor 1000 or so larger than one would expect based on then common intuitive notions. The trick that he used was first to impose microwave power on the nuclear-electron system and thereby excite the electronic spins to higher, non-thermal equilibrium states. Then because of the coupling between the electron and the nuclear spins, as the excited electron spins try to equilibrate to their lower states they reorient the nuclear spins. The nuclear spins then exhibit an enhanced polarization by a factor equal to the ratio of the electronic to the nuclear magnetic moments i.e., by about a factor of $\cong 1000$.

When first proposed as a contributed paper at an APS meeting in April 1953, the proposal was met with much skepticism by a formidable array of physics talent.

Possible effects of a CDW on the physical properties of poatassium

Fourfold induced-torque anisotropy

Cyclotron-resonance transmission- effect of a CDW

Microwave surface resistance in a perpendicular magnetic field: effect of the CDW

Quantum oscillations from the cylindrical Fermi surface sheet created by a CDW

Neutron diffraction structure in K near 011 and 022 Bragg points

Fermi surface in K in the CDW state

Infrared absorption spectrum of an ICDW in K

Field dependence of the residual resistivity anomaly in K

Photoemission from the CDW in K and Na

The T dependence of the resistivity below 1.3K rules out the conventional e-e scattering which is explained by the electron-phason scattering resistivity which depends on the anisotropy of the phason spectrum (PRB 23, 3638 (1981)

Direct Observation of the Charge-Density Wave in Potassium by Neutron Diffraction

T. M. Giebultowicz,[1,2] A. W. Overhauser,[2] and S. A. Werner[1,3]
[1]*National Bureau of Standards, Gaithersburg, Maryland 20899*
[2]*Department of Physics, Purdue University, West Lafayette, Indiana 47907*
[3]*Department of Physics and Astronomy, University of Missouri, Columbia, Missouri 65211*
(Received 13 January 1986)

Sharp charge-density-wave satellites in potassium have been located at (0.995, 0.975, 0.015). They are smaller than the {110} reflections by $\sim 10^5$, and each is surrounded by a prolate ellipsoidal cloud of diffuse phason scattering having its major axis along a line through the point (1,1,0).

PHYSICAL REVIEW B VOLUME 35, NUMBER 17 15 JUNE 1987-I

Search for charge-density waves in potassium by neutron diffraction

L. Pintschovius
Kernforschungszentrum Karlsruhe, Institut für Nukleare Festkörperphysik, Postfach 3640, D-7500 Karlsruhe, Federal Republic of Germany and Laboratoire Léon Brillouin, Centre d'Etudes Nucléaires de Saclay, F-91191 Gif-sur-Yvette Cedex, France

O. Blaschko and G. Krexner
Institut für Experimentalphysik der Universität Wien, Strudlhofgasse 4, A-1090 Wien, Austria

M. de Podesta
H. H. Wills Physics Laboratory, University of Bristol, Bristol BS8 1TL, United Kingdom

R. Currat
Institut Laue-Langevin, F-38042 Grenoble Cedex, France
(Received 9 March 1987)

The recently reported direct observation of charge-density waves in potassium by neutron diffraction was checked by high-resolution neutron-diffraction experiments. The observed diffraction pattern is not due to charge-density-wave satellites, but due to double-scattering processes. After eliminating these processes we searched for the charge-density-wave satellites in the theoretically predicted region, but found none. The intensity of any undetected satellites must be at least 2 orders of magnitude lower than predicted.

Motivation for carrying out the aforementioned experiment was summarized in a survey of reported alkali-metal anomalies. Published experiments, if all are accepted at face value, provide a spectacle of theoretical failure. None have been explained within the conventional framework—a nearly spherical simply-connected Fermi surface. In contrast, the CDW model provides a unified (and for the most part quantitative) explanation of all of them. But this is entirely circumstantial. If the atoms are displaced from their cubic sites, those displacements must be seen. The field-modulation experiment should successfully separate myth from reality.

PHYSICAL REVIEW B VOLUME 3, NUMBER 10 15 MAY 1971

Observability of Charge-Density Waves by Neutron Diffraction

A. W. Overhauser
Scientific Research Staff, Ford Motor Company, Dearborn, Michigan 48121
(Received 7 December 1970)

It is shown that atomic displacements $\vec{A}\sin\vec{Q}\cdot\vec{L}$ associated with a charge-density wave (CDW) modulation of a metal crystal cause several changes in the anticipated diffraction properties. Very weak satellite reflections should occur at locations $\pm\vec{Q}$ from the ordinary (cubic) reflections. However it is found that vibrational excitations, corresponding to phase modulation of the CDW, may weaken the satellite intensities below the level of observation. The structure factors of the cubic reflections are reduced from unity to (the Bessel function) $J_0(\vec{K}\cdot\vec{A})$, where $\vec{K}$ is the scattering vector. Measurements of structure factors are difficult to interpret in the alkali metals because of severe primary extinction (mosaic block size ~ 0.5 mm) and unknown anharmonic contributions to the Debye-Waller factor. Nevertheless, an unambiguous test for CDW structure is possible since $\vec{Q}$ (and $\vec{A}$) must be orientable by a large magnetic field at 4 °K. Consequently high-index Bragg reflections should be turned off or on by a magnetic field rotated parallel or perpendicular to $\vec{K}$. Motivation for such an experiment is suggested by a survey of electronic anomalies which have been reported in the alkali metals and which can be explained with the CDW model.

PHYSICAL REVIEW B **66**, 165115 (2002)

Theory of the fourfold induced-torque anisotropy in potassium

A. W. Overhauser
Department of Physics, Purdue University, West Lafayette, Indiana 47907

Graciela Lacueva
Physics Department, John Carroll University, University Heights, Ohio 44118
(Received 15 July 2002; published 30 October 2002)

Induced-torque anisotropies observed in single-crystal spheres of potassium prove that the Fermi surface is multiply connected. Cyclotron orbits which intersect heterodyne gaps created by the charge-density-wave broken symmetry lead to an anisotropic Hall effect having longitudinal components. Thereby the theoretical induced torque (in a 360° magnet rotation) has four evenly spaced minima and four maxima with a staggered spacing. The maxima grow almost $\sim H^2$ and can be 30 times higher than the minima. All such features have been observed. (Details depend on crystal growth and orientation.) All are impossible in a spherical crystal with a simply connected Fermi surface.

The last paper

“Perhaps the most reproducible property of potassium is its irreproducibility” ‘AW Overhauser, Adv in Physics 27,343 (1978)

Not only results depend from sample to sample but vary drastically from run to run on the same sample.
Alkali metals continuously recrystallize at room temperature

The resistance ratio of a wire can depend on whether it was cooled at 4K quickly or slowly , coated with oil or dry or how long time it was kept at room temperature

Potassium: Admirable perseverance in the goal to be reached

Back to Chromium:

the need of a nanowire with a single Q vector