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Quantum Electronic Solids

07 March 2013

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AFOSR/RTD**

Air Force Research Laboratory

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2013 AFOSR SPRING REVIEW 3001H PORTFOLIO OVERVIEW



NAME: Quantum Electronic Solids

BRIEF DESCRIPTION OF PORTFOLIO:

Physics and electronics at the nanoscale: superconductivity, metamaterials and nanoelectronics - exploiting quantum phenomena to create faster, smarter, smaller and more energy-efficient devices

SUB-AREAS IN PORTFOLIO:

Superconductivity: find more-useful materials for high magnetic fields, microwave electronics, power reduction and distribution

Metamaterials: microwave, IR & optical sensing and signal processing with smaller sizes and unique properties

Nanoelectronics: NTs, graphene, diamond, SiC for sensing, logic & memory storage



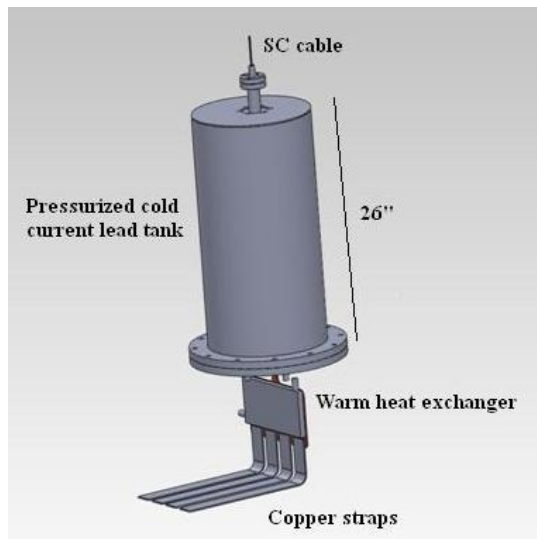
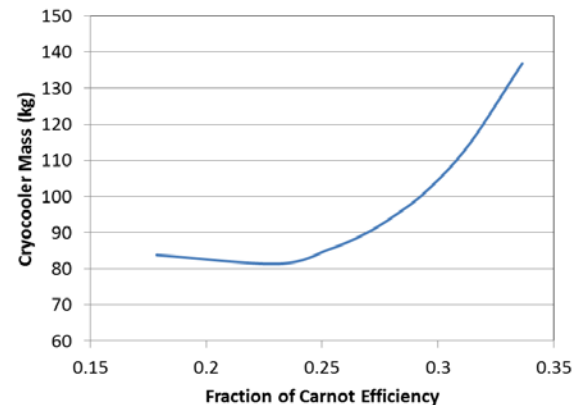
SC Power Transmission for DE



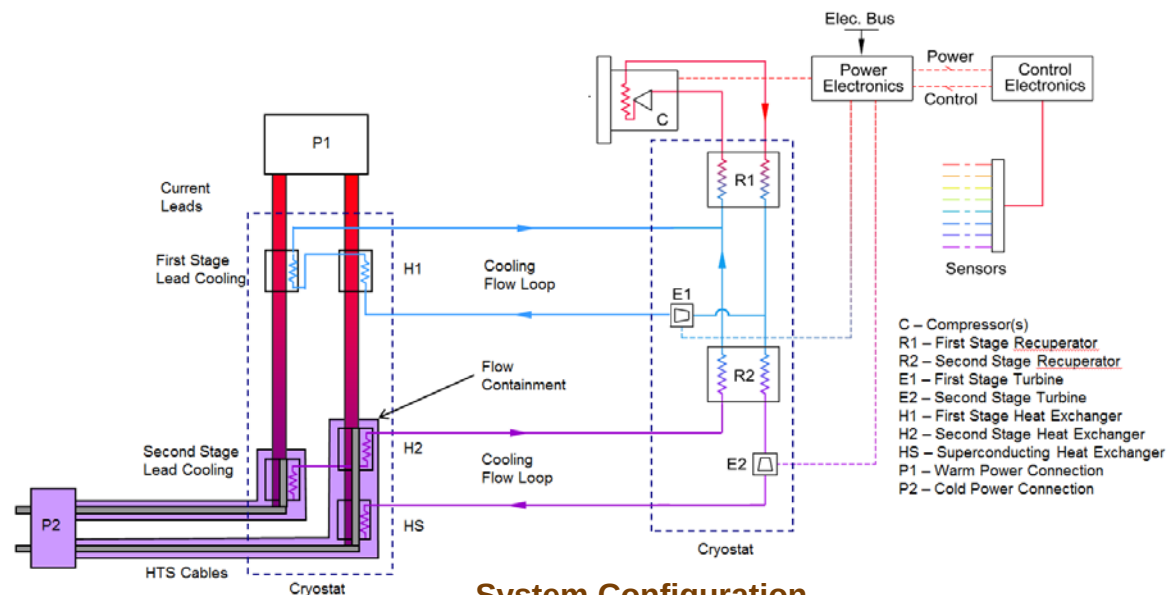
A. Dietz, Creare Inc., L. Bromberg, MIT

- Two-stage current leads with integrated heat exchangers cooled by cycle gas from a two-stage turbo-Brayton cryocooler
- Current lead design minimizes cold heat load and ensures even current distribution
- Cryocooler design offers high efficiency with low weight
- Advantages over copper cables
 - 90% less weight
 - 40% less power consumed

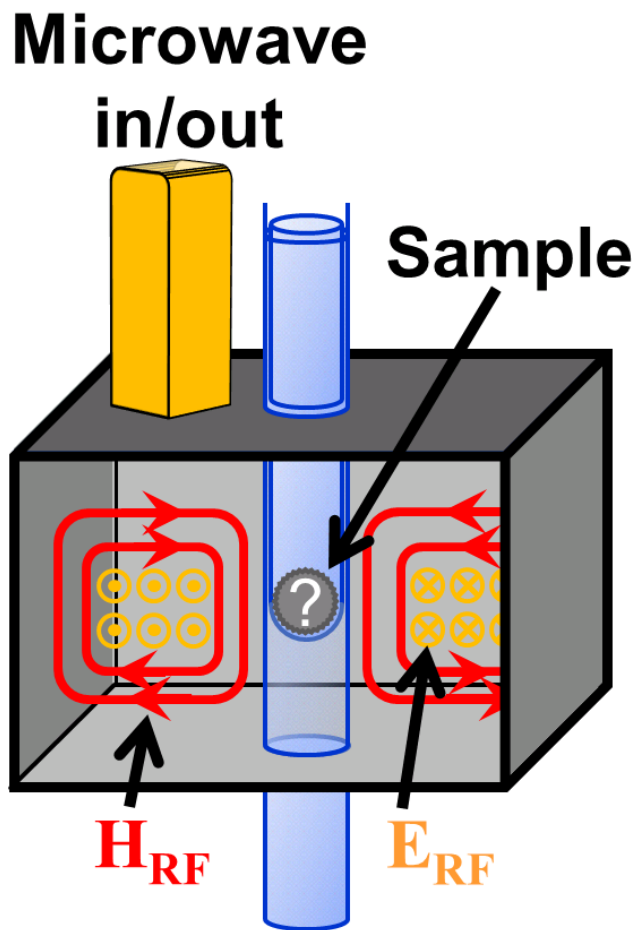
Cryocooler Performance



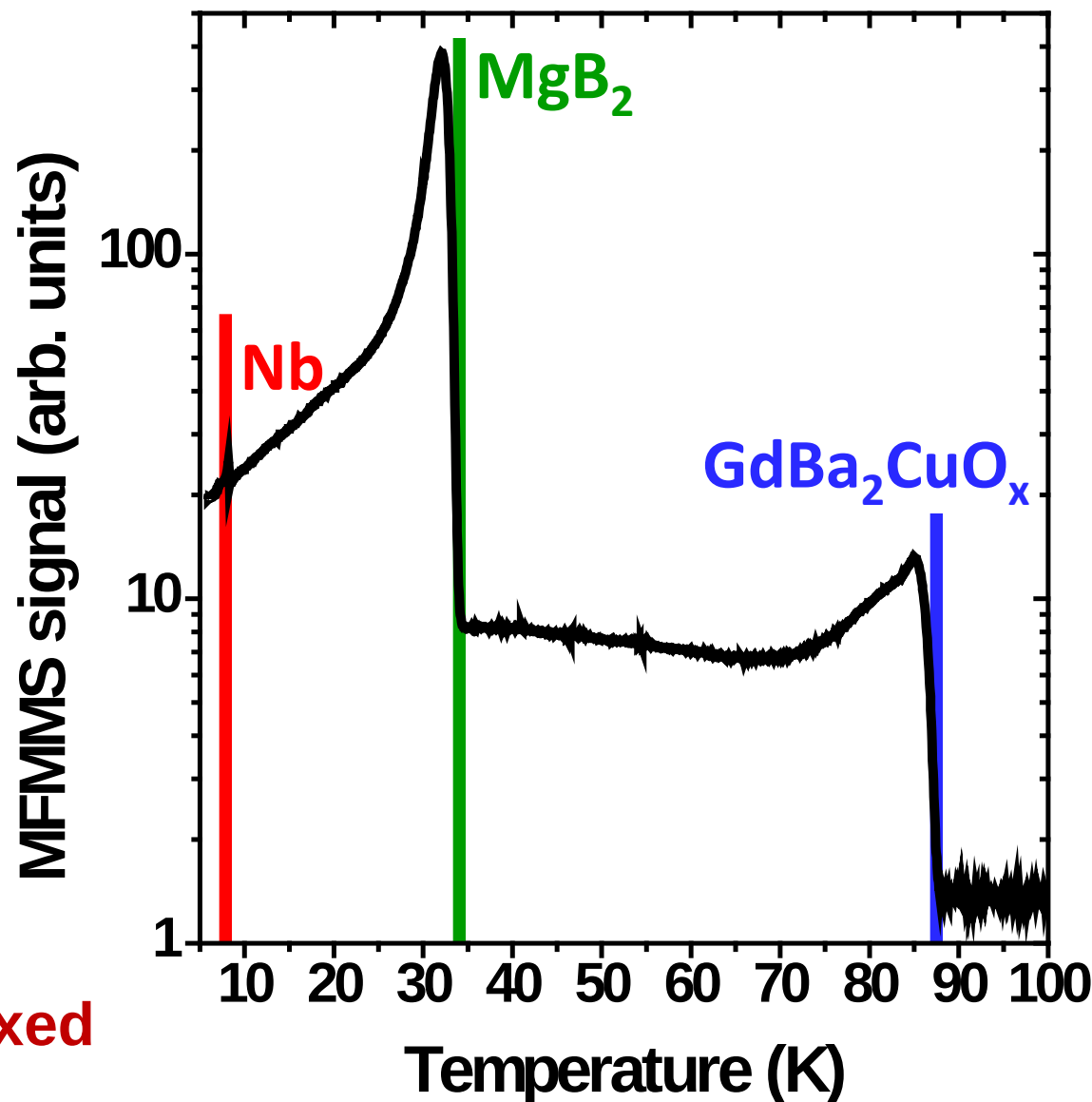
Current Lead Design



System Configuration



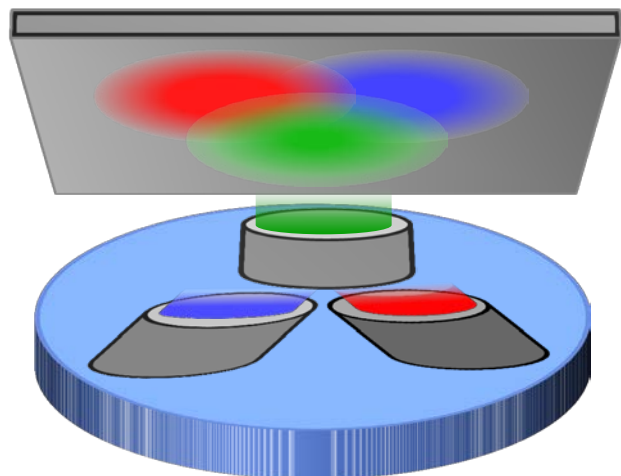
Study of intimately mixed superconductors





MURI Supersearch New Superconductors Discovered

Ivan K. Schuller, UCSD



Phase Spread Alloys



Bulk Synthesis



- High-Pressure
- High-Temperature



MFMMS

Discoveries (#):
Borides (10), Carbides (6),
Chalcogenides (4),
Silicides (2), Bismuthates(1),
Antimonides (1),
Other Intermetallics (2)



Meteorites

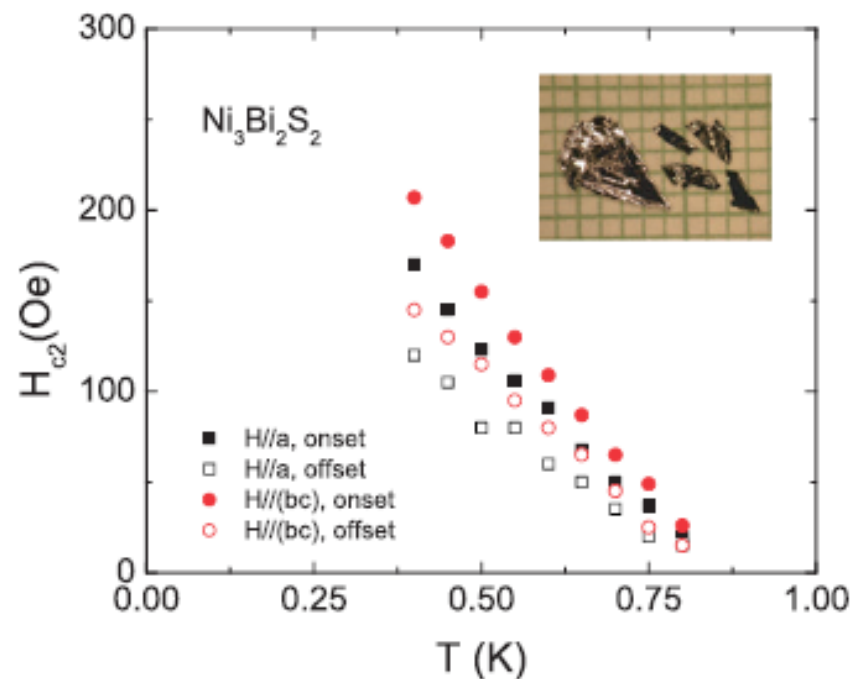
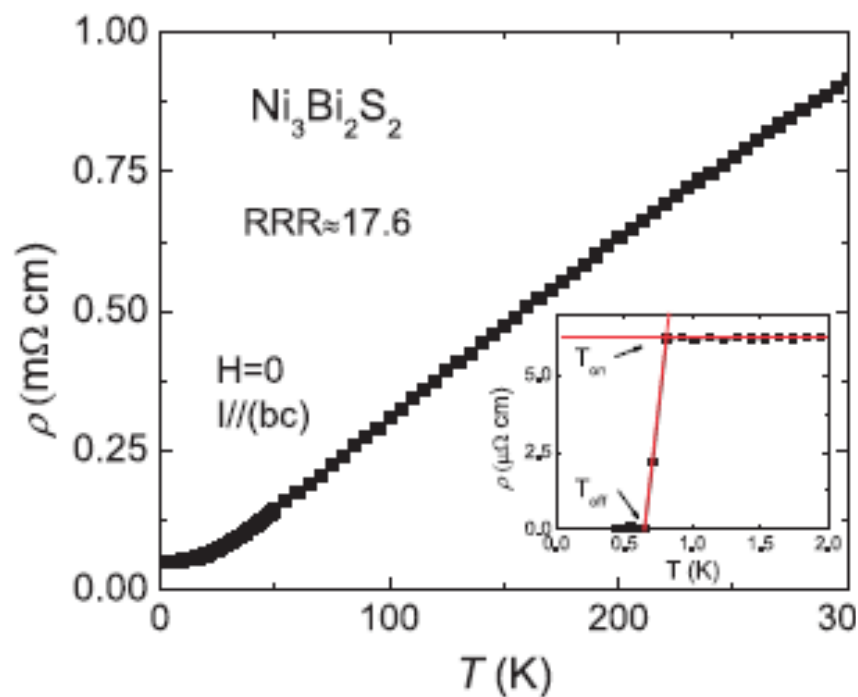


Empirical Search for New Superconductors

U Maryland-Iowa State-UC San Diego MURI (PI-R.L. Greene)



Development of viable solutions for the synthesis of sulfur-bearing single crystals
Xiao Lin, Sergey L. Bud'ko and Paul C. Canfield*



Have grown single crystals of mineral types: Parkerite (above, SC below 1K), Shandite, Paracostibite, and sulfide variants of olivine (not shown and not SC).

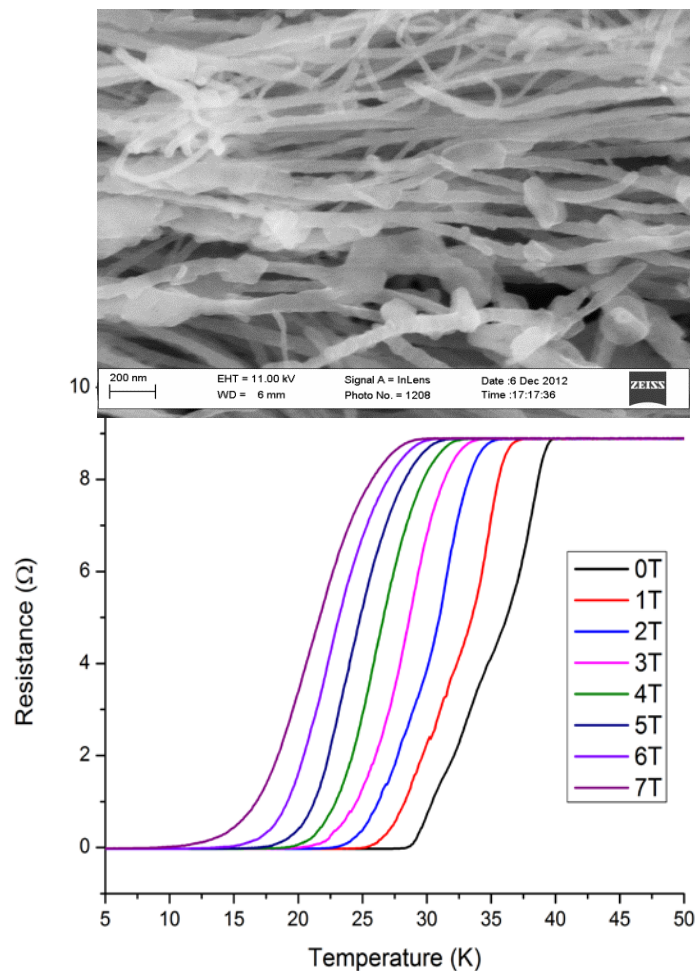


Superconducting Flexible Wire: MgB_2 @CNT; FeSe @CNT



A. Zakhidov, University of Texas at Dallas

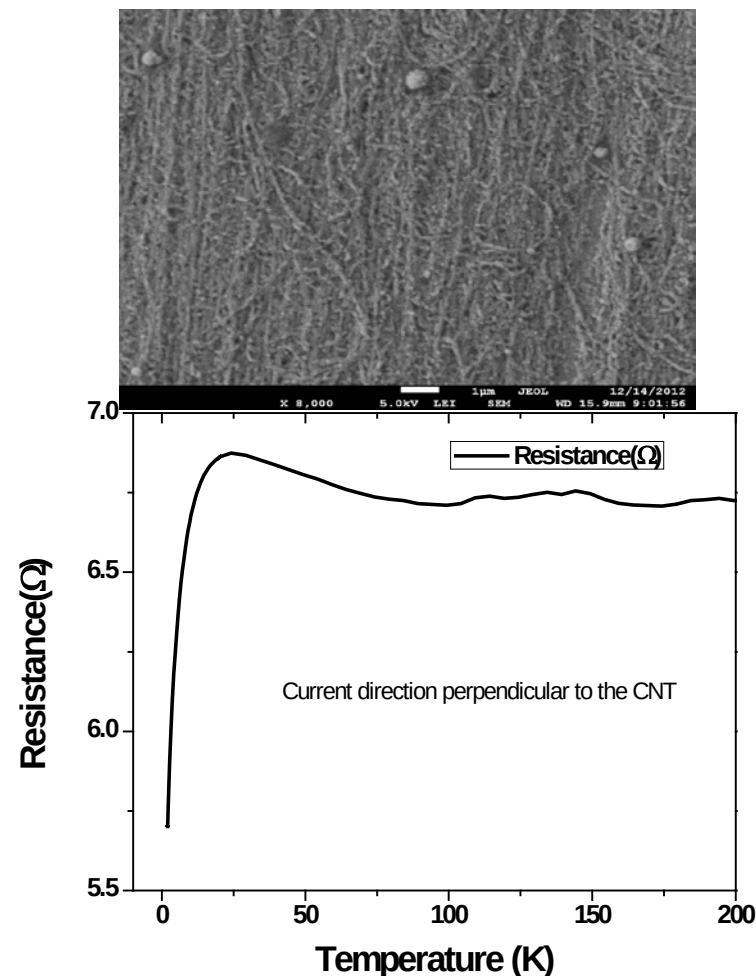
MgB_2 nanowires



Resistance drops to exact zero after RF oxygen plasma treatment,

DISTRIBUTION STATEMENT A – Unclassified, Unlimited Distribution

$\text{FeSe}_{0.5}\text{Te}_{0.5}$ on CNT

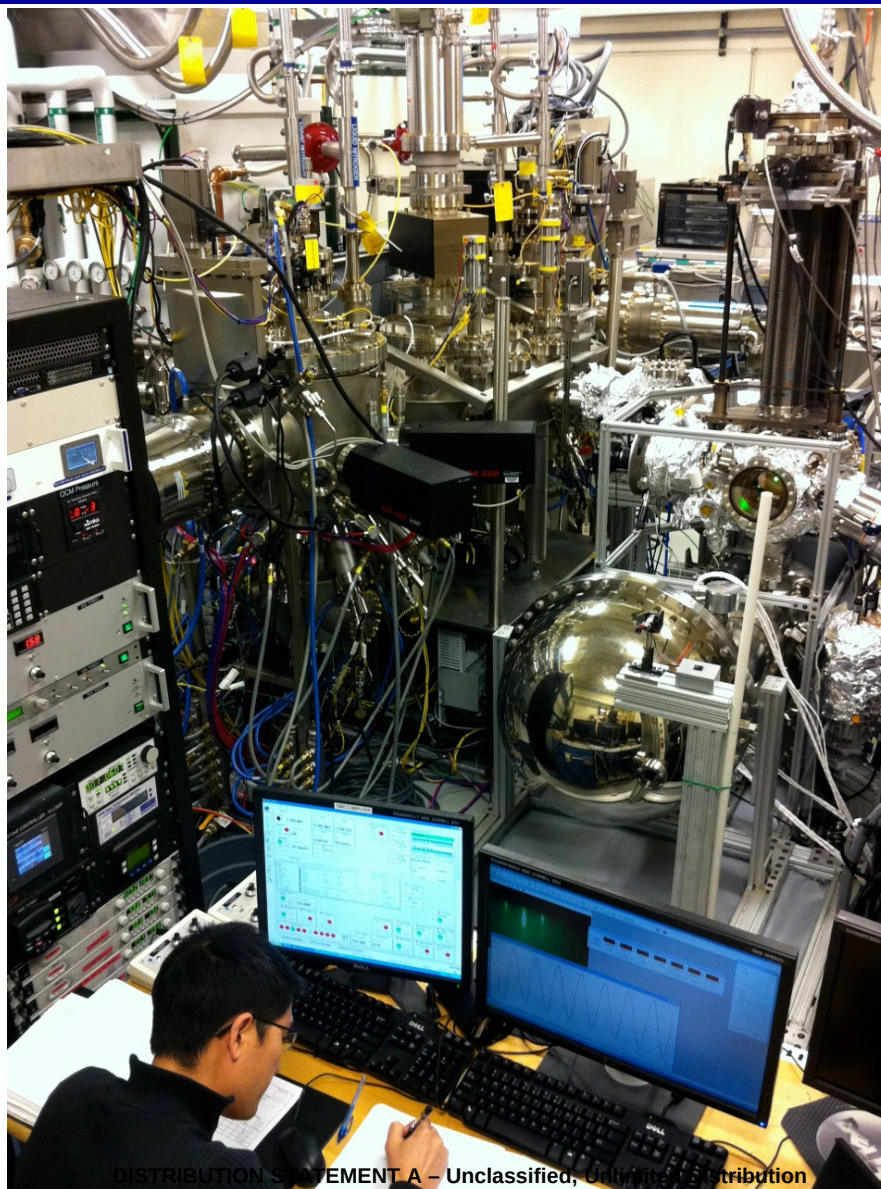


Resistance drops at T_c but not to zero :
needs optimization of barrier coating.



Integrated MBE – ARPES

Kyle Shen, Cornell U.



DISTRIBUTION STATEMENT A – Unclassified, Unlimited Distribution

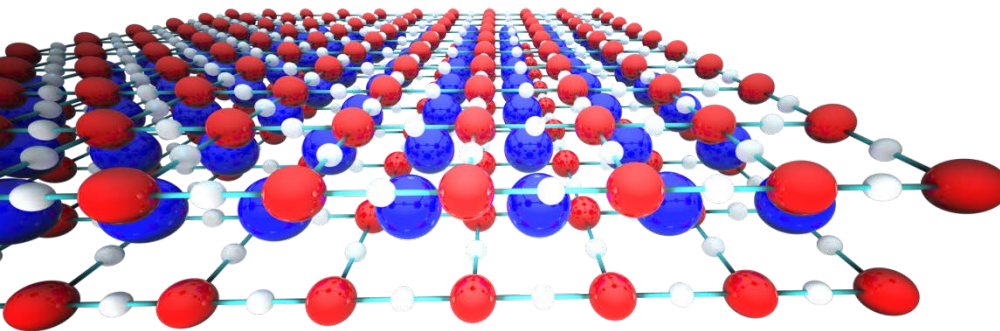


Investigating the “Mother” of all High- T_c Superconductors

Kyle M. Shen, Cornell University



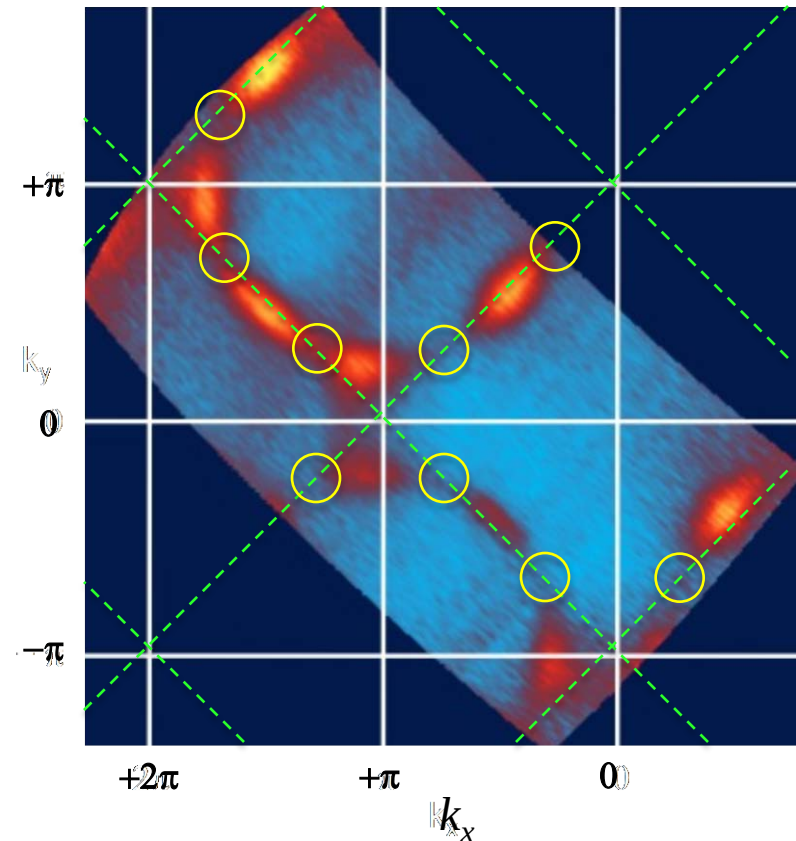
$\text{Sr}_{1-x}\text{La}_x\text{CuO}_2$ epitaxial thin films



Cu O Sr / La

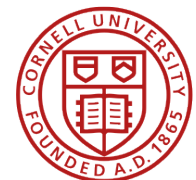
- Simple, archetypal structure of cuprates (square, flat CuO_2 sheets)
- Can be doped either with holes or electrons (only ambipolar SC cuprate)
- Bulk single crystals do not exist (epitaxial stabilization)

ARPES measurements



Regions of suppressed intensity on the Fermi surface (yellow circles) indicate presence of strong antiferromagnetic fluctuations

J.W. Harter *et al.*, *Phys. Rev. Lett.* (in press)



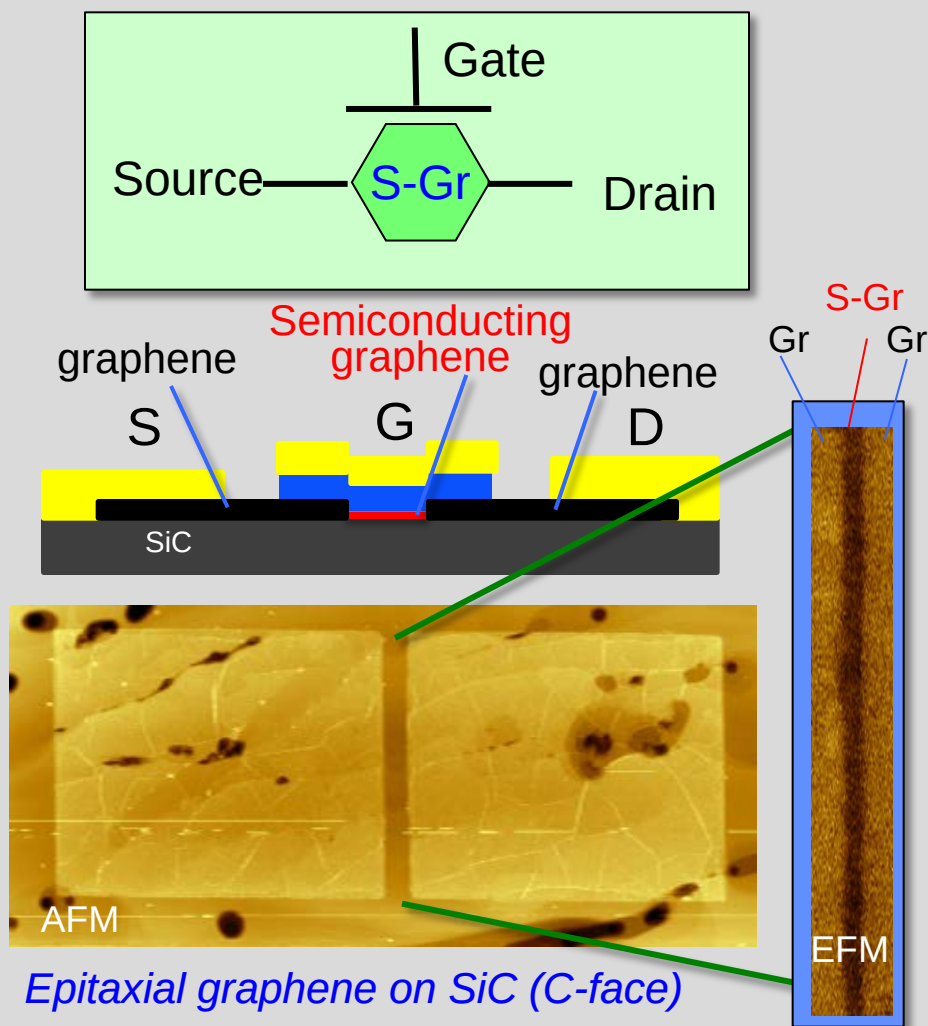


Semiconducting Graphene (S-Gr)

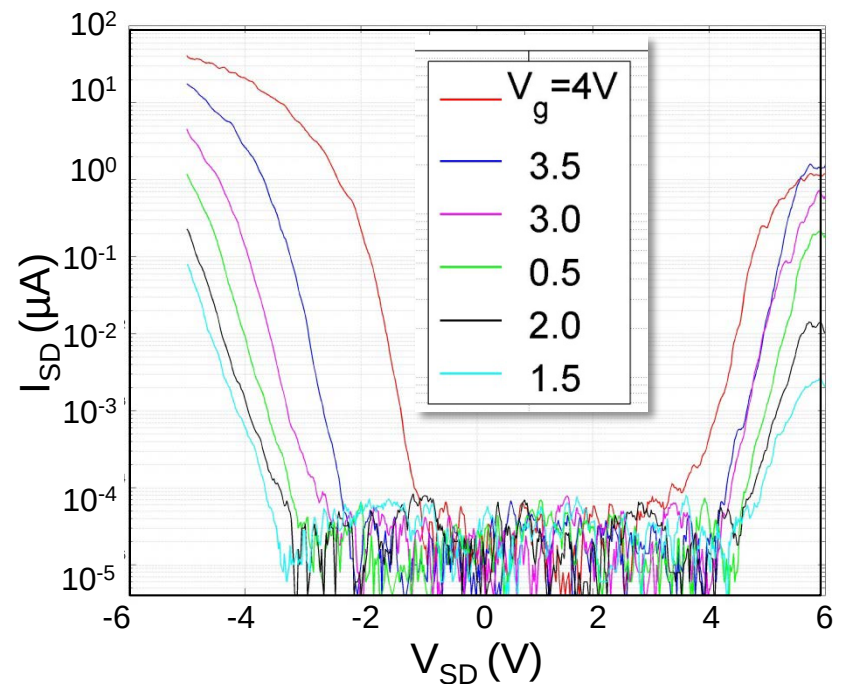
Walt de Heer, Georgia Tech



- SGr (bandgap~1eV) is graphene that is bonded to the SiC surface.
- It *seamlessly* connects to graphene to make atomically thin, gateable SGr-Gr junctions.
- Digital electronics is feasible; • SGr is stable at extreme temperatures;



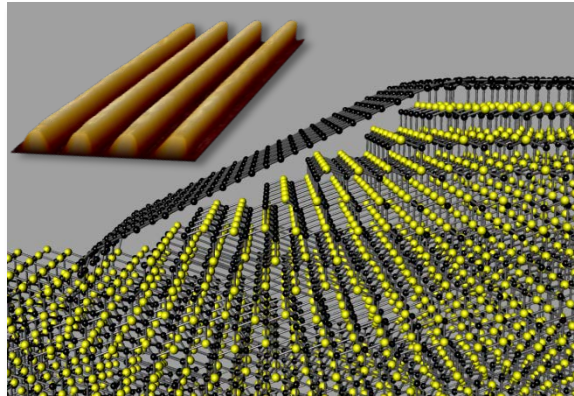
*On-off ratio $> 10^5$
Factor 10^4 greater than
for pure graphene FETs.*



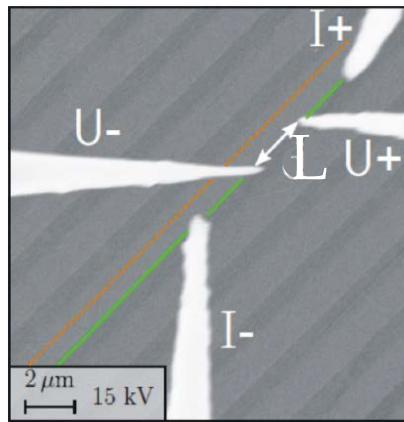


Room Temp Ballistic Transport in Graphene Nano-ribbons

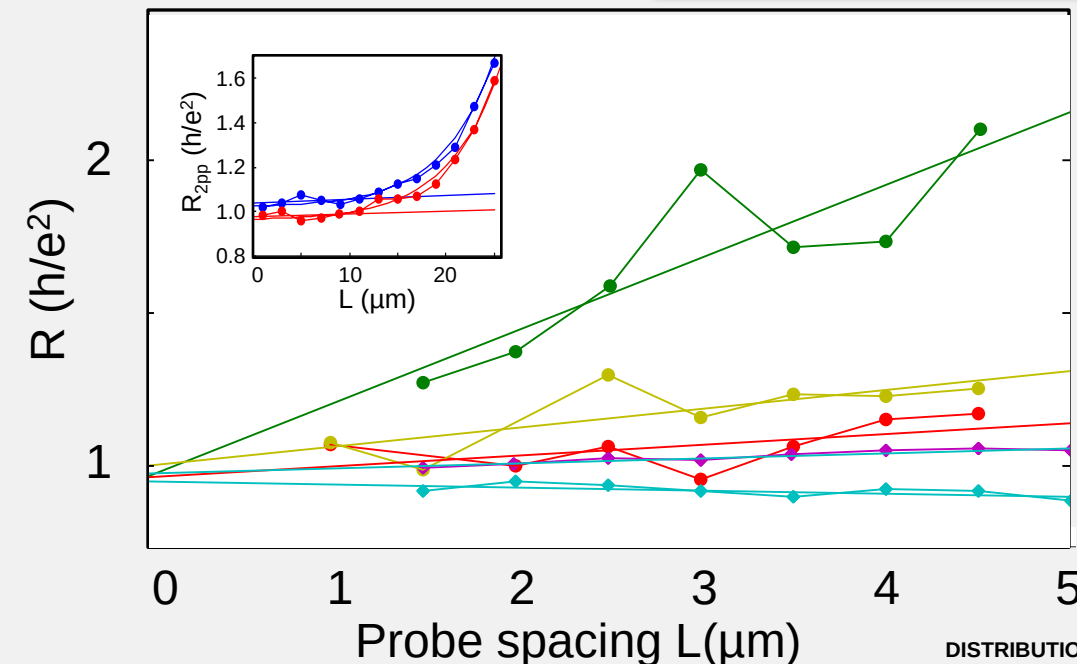
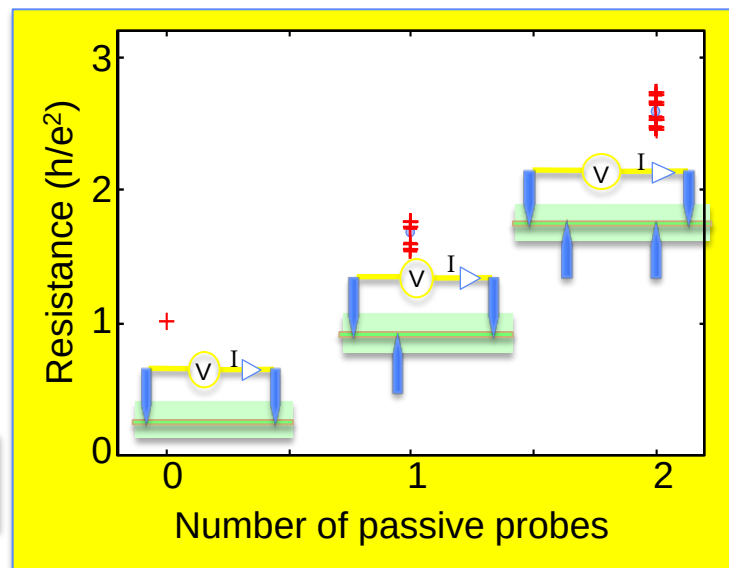
Walt de Heer, Georgia Tech



Graphene on crystallized sidewall



SEM image of four nano probes contacting graphene ribbon



• 40 nm wide graphene ribbons grown on crystallized sidewalls of trenches etched in SiC are ballistic conductors.

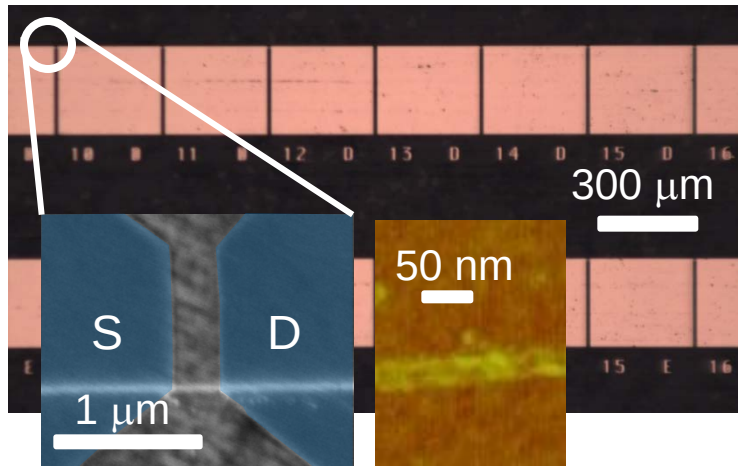
• Resistances ($\approx h/e^2 = 25.8 \text{ k}\Omega$) are essentially independent of length and temperature.

• Touching a ribbon with a probe, scatters electrons and (reversibly) doubles the resistance. Touching it with 2 probes, triples it.

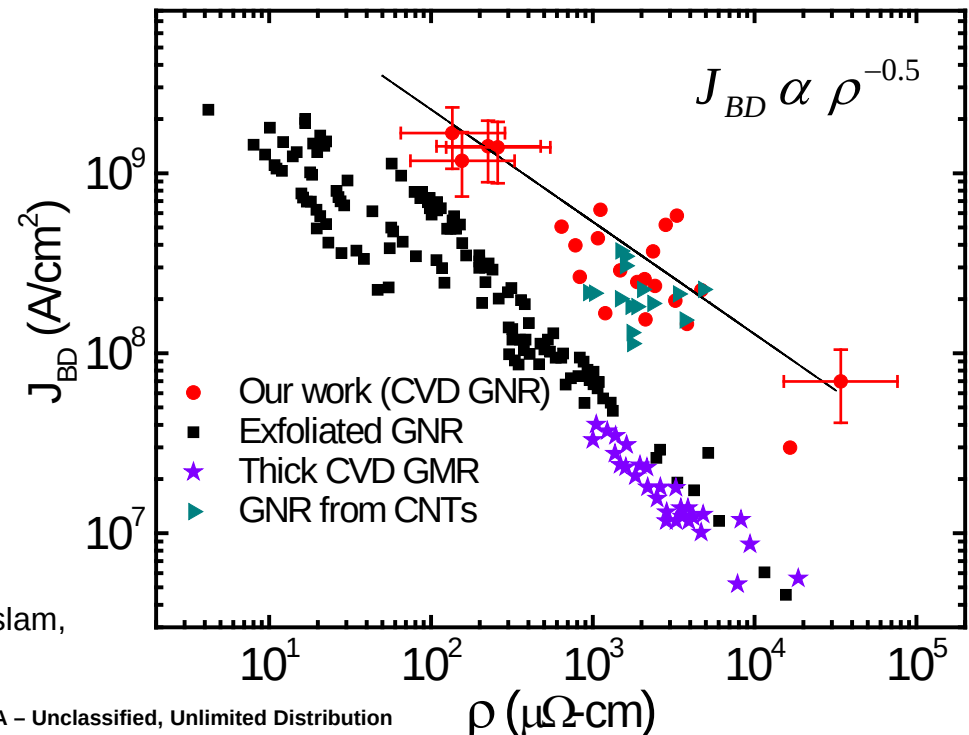
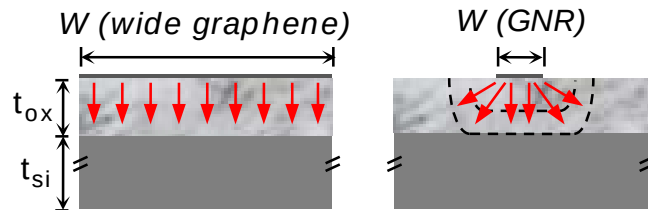


Nanoscale Interconnects from CVD Graphene

Eric Pop, UIUC



- First study of large-scale graphene nanoribbon (GNR) interconnects from graphene grown by chemical vapor deposition (CVD)
- Examined temperature range 2-900 K



See: A. Behnam, A. S. Lyons, M-H. Bae, E. K. Chow, S. Islam, C. H. Neumann, E. Pop, *Nano. Lett.* 12, 4424 (2012).

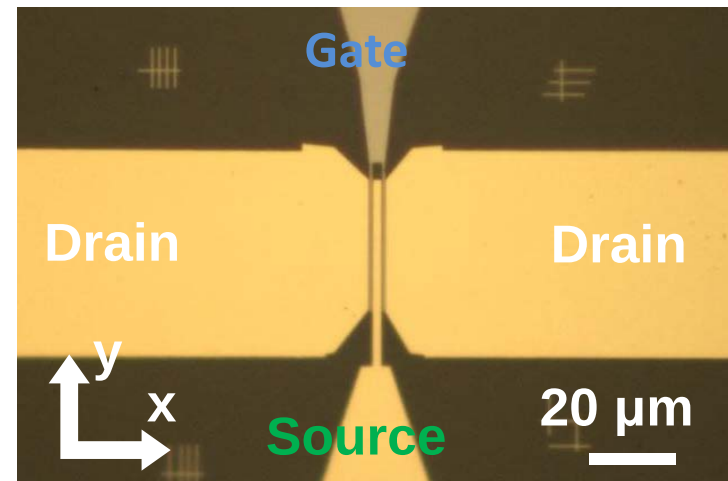
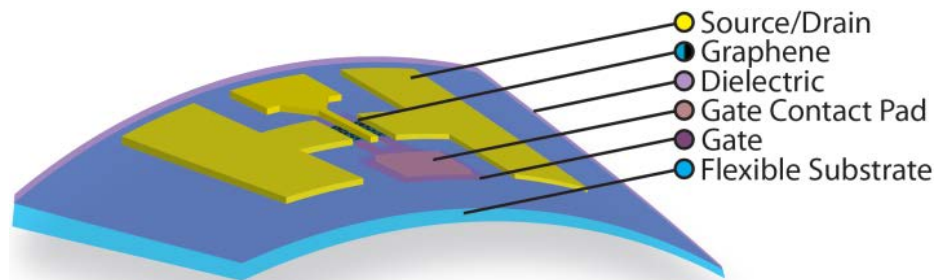


Graphene Yields High Performance Flexible FETs

Ken Shepard and Jim Hone, *Columbia University*



Inherent flexibility of monolayer graphene, and its environmental inertness, make it a natural candidate for flexible electronics. GHz frequency response can be obtained with little sensitivity to strain, a major advance in flex-FET speed.



Questions: Stress, Performance, Fabrication

- Back gate (gold-palladium alloy), PEN substrate
- Hafnium-oxide gate dielectric
- CVD graphene transferred over gates

Performance

- f_T , f_{max} of 10.7 GHz, 3.7 GHz w/o de-embedding
- $f_T/f_{max}=0.35$, entire strain range.
- Mobility, output resistance unchanged by strain; $g_m \sim 1/2$ its 0% strain value at $\sim 2\%$ strain

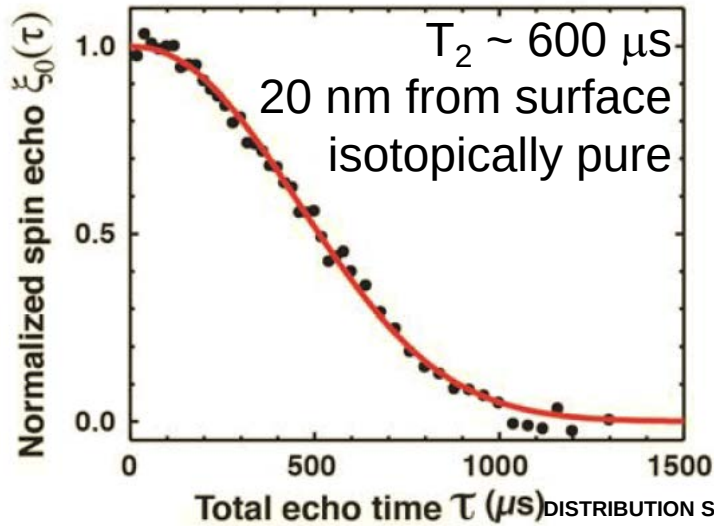
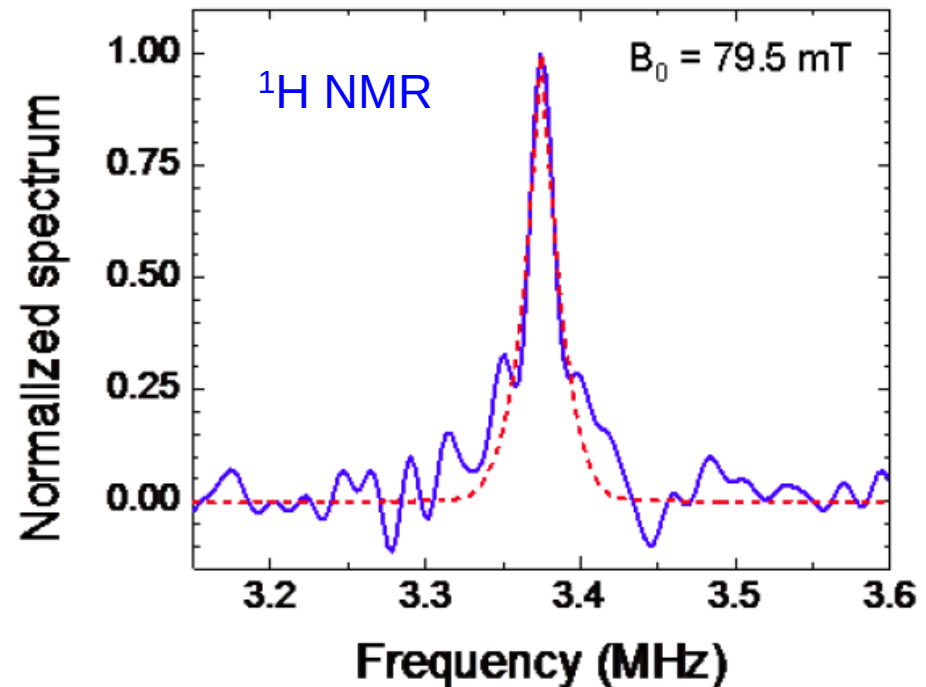
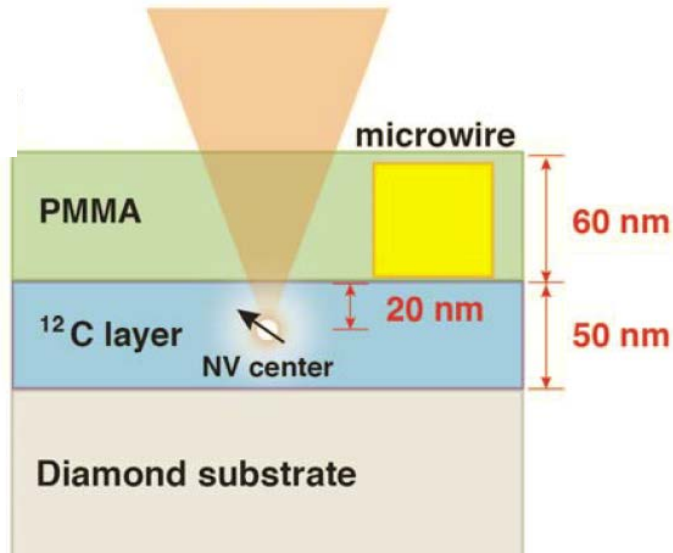


Nanoscale NMR with a Single Electron Spin Sensor

D. D. Awschalom, *University of California – Santa Barbara*



532 nm excitation
Fluorescence readout



- Room temperature detection of external protons
- No magnetic field gradients needed
- 13 nm³ detection volume PMMA ~8nT sensitivity
- Collaboration with IBM Research Division

Science, in press (2012)



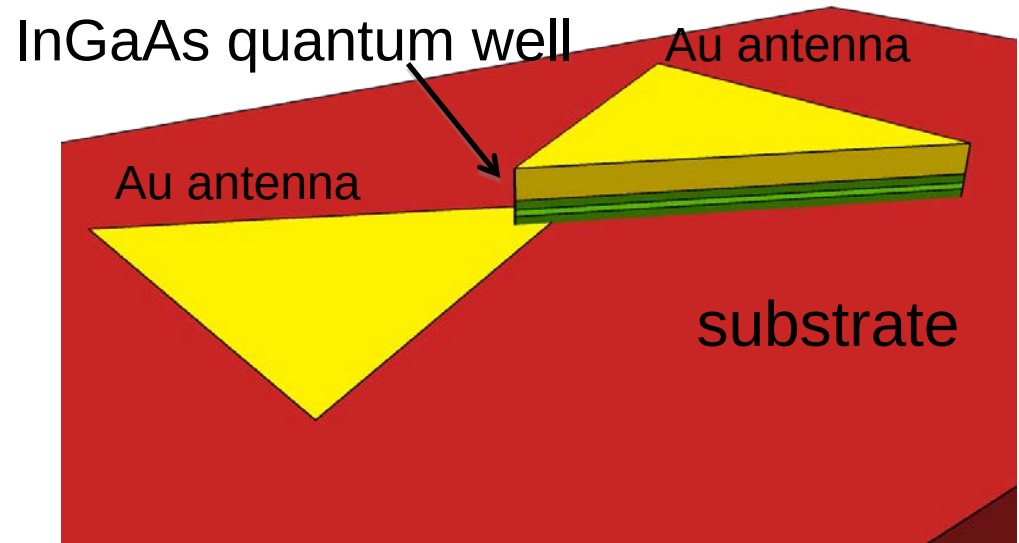
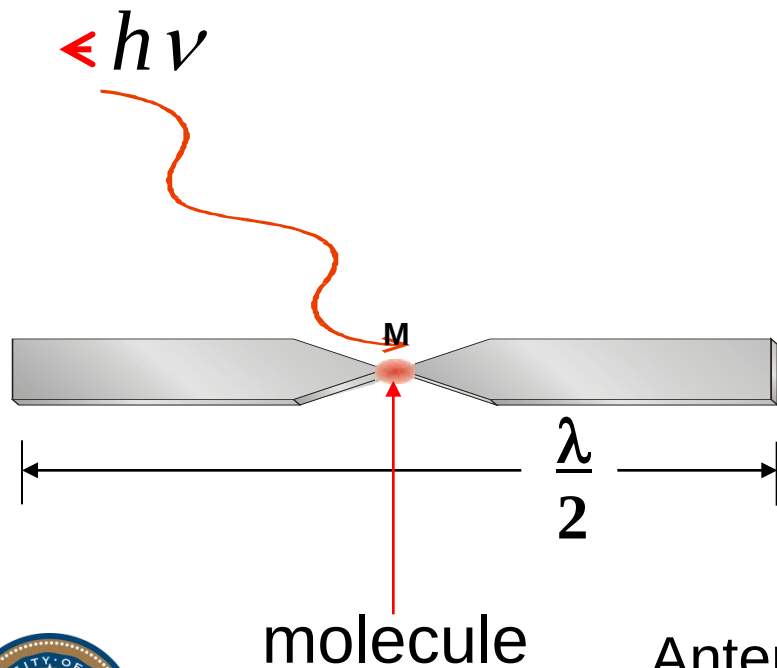


Spontaneous Hyper-Emission

Eli Yablonovitch & Ming Wu, UC Berkeley



Using an optical antenna, Spontaneous Emission Rate can be $\sim 0.1 \times \omega_0$!!!
Faster than stimulated emission, but antenna slot must be very narrow.



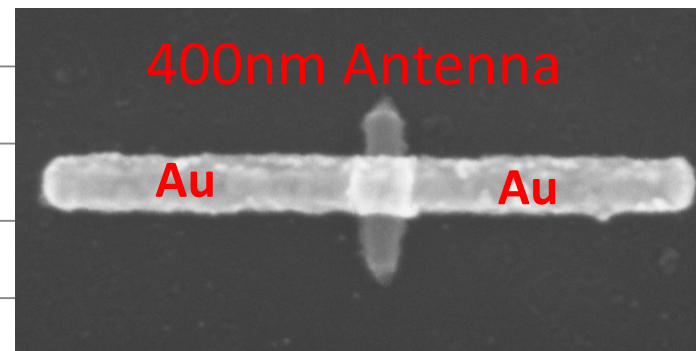
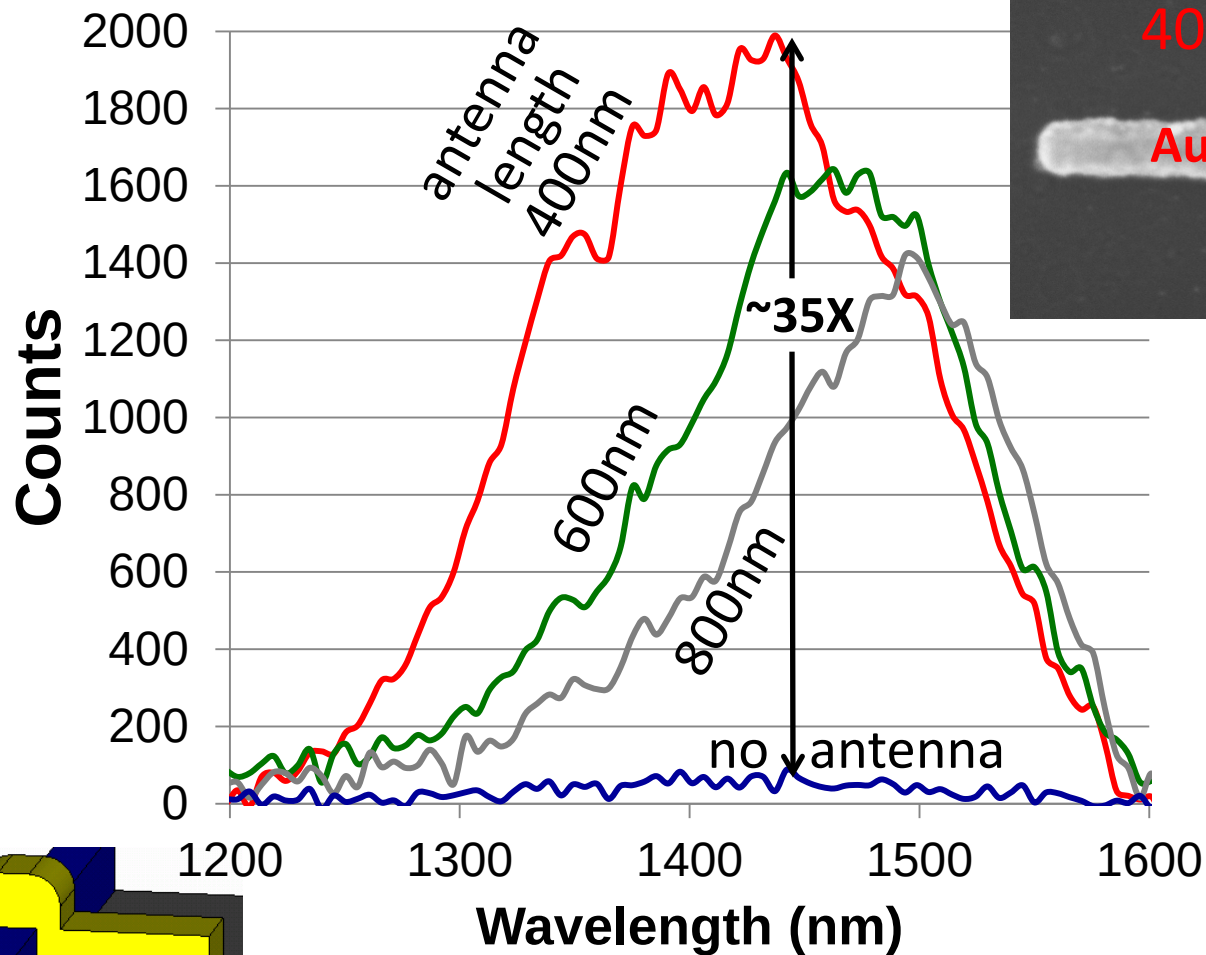
Antenna slot defined by quantum well thickness!





Single Arm Antenna

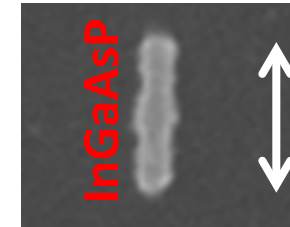
Eli Yablonovitch & Ming Wu, UC Berkeley



Emission Parallel to Antenna

Pump Polarization

no antenna

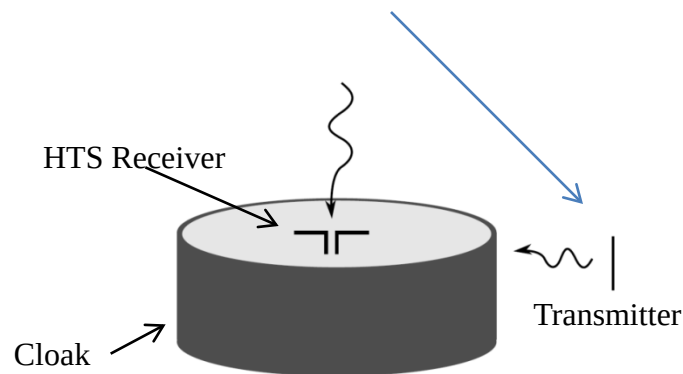


~35X Spontaneous Emission Enhancement

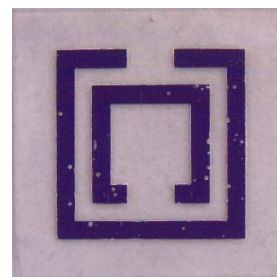


Protecting Superconducting Antennas with Metamaterial Cloaks

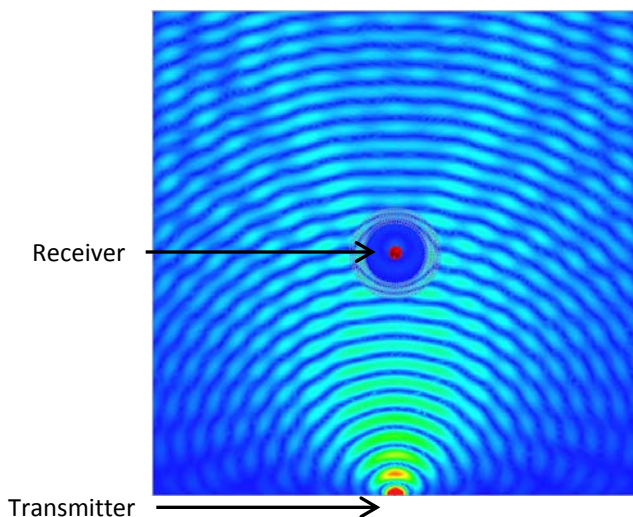
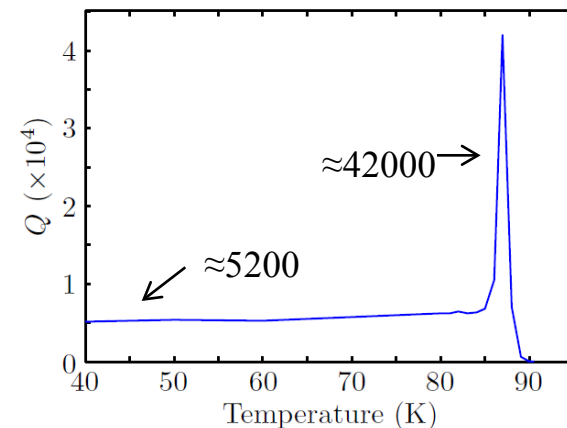
Frank Trang, Horst Rogalla, Zoya Popovic, University of Colorado, Boulder



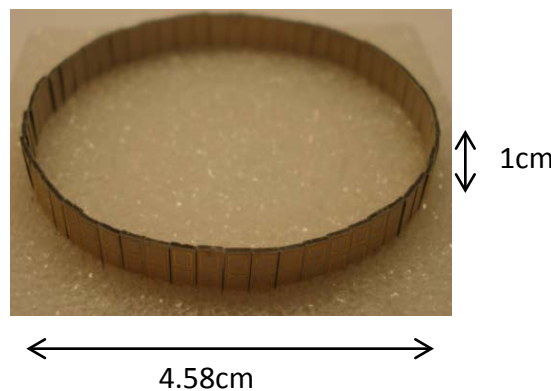
Proposed cloak geometry



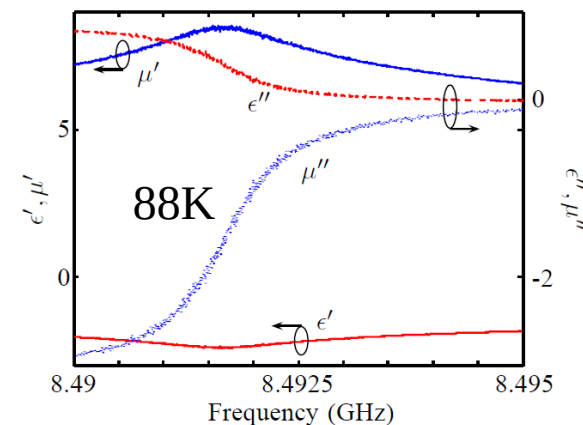
HTS Split Ring Resonator (SRR) and its temperature dependent quality factor Q



Simulated EM-field: the far field is restored behind the cloak



One of 5 layers of the proposed cloak constructed of SRRs.

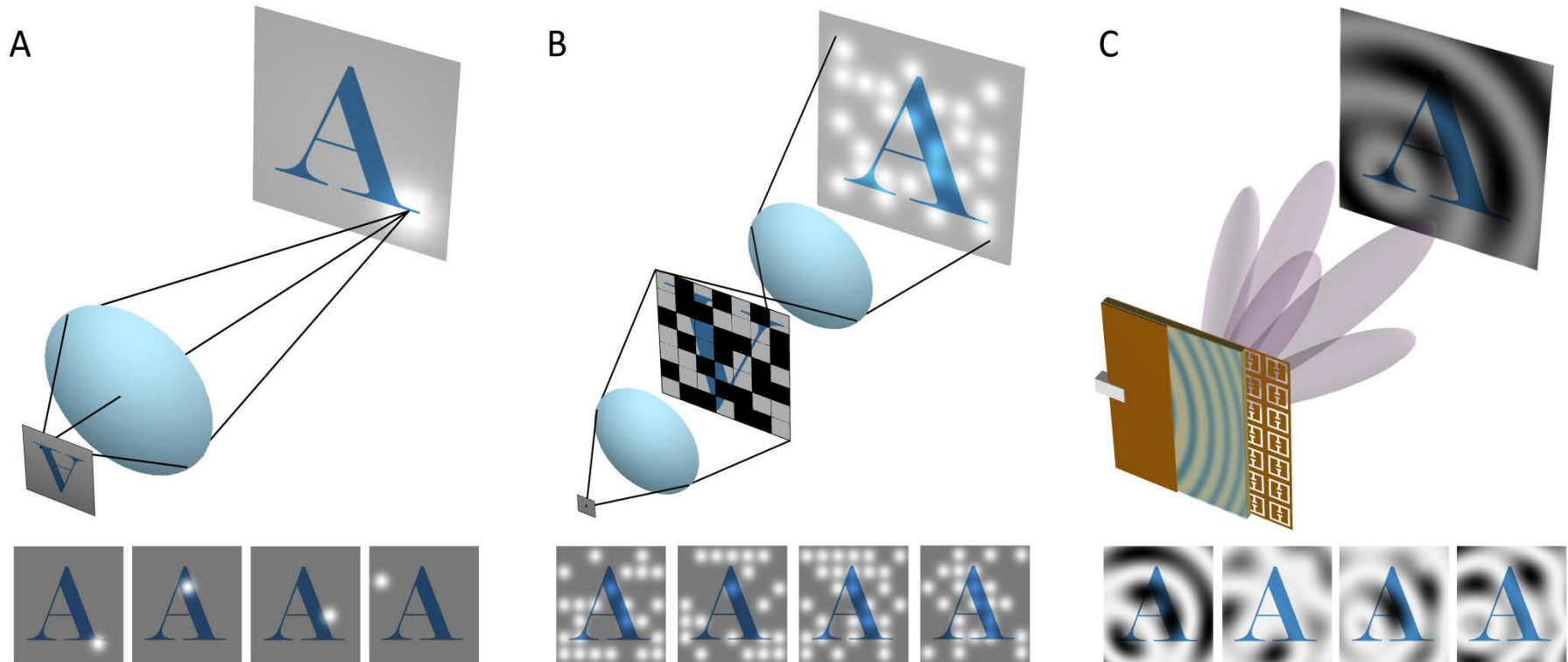


Parameter extraction of μ and ϵ



Metamaterials for Computational Imaging

D. R. Smith, *Duke University*

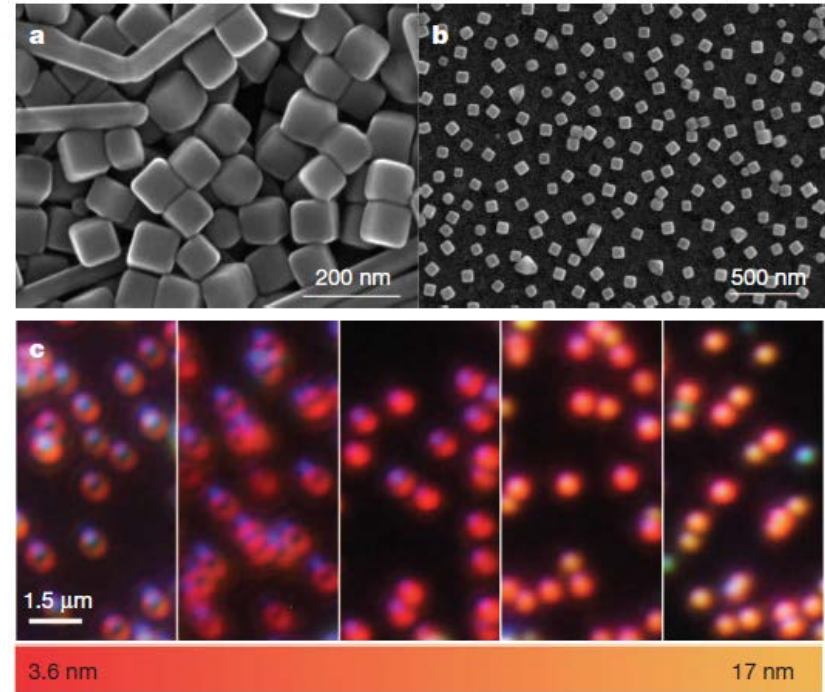
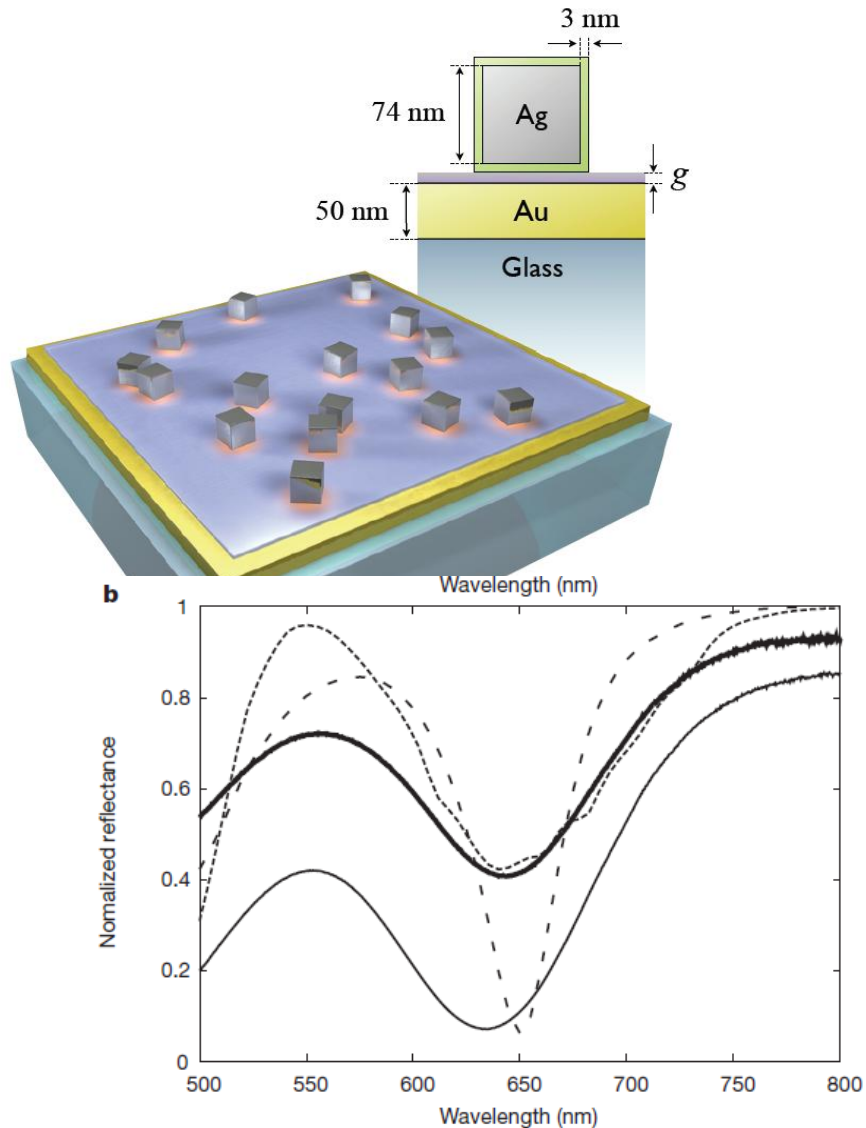


Comparison of (A) conventional, (B) single pixel, and (C) metamaterial imagers. In the metamaterial imager, a set of randomized modes sequentially samples a scene. Scene data can subsequently be reconstructed using sparse algorithms. The imager shown makes use of frequency-diversity to sample an image: no active tuning or mechanical scanning is necessary—just a frequency sweep.



Approaches to Large Area Absorber Materials

David R. Smith, Duke University



Film-coupled nanocubes can produce strong absorption resonances that can create surfaces with controlled reflectance. The advantage is that perfect absorbing materials with large surface area can be fabricated cheaply and easily.

A. Moreau *et al.*, *Nature* (2012)



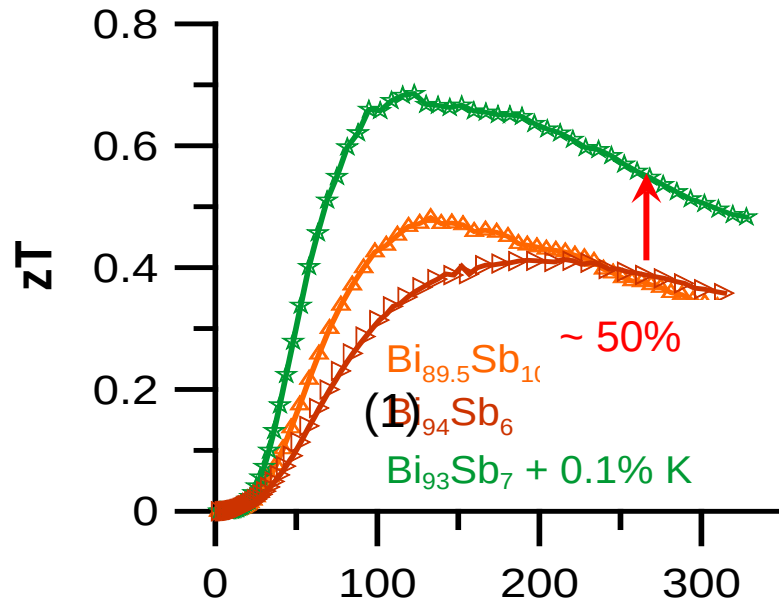
Cryogenic Peltier Cooling: record zT

J. P. Heremans *Ohio State*; D. T. Morelli, *Michigan State*

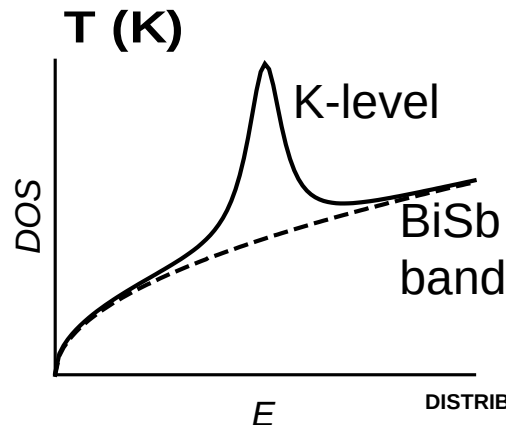
Record Thermoelectric Figure of Merit $zT \equiv T S^2 \sigma / \kappa$ below 150 K



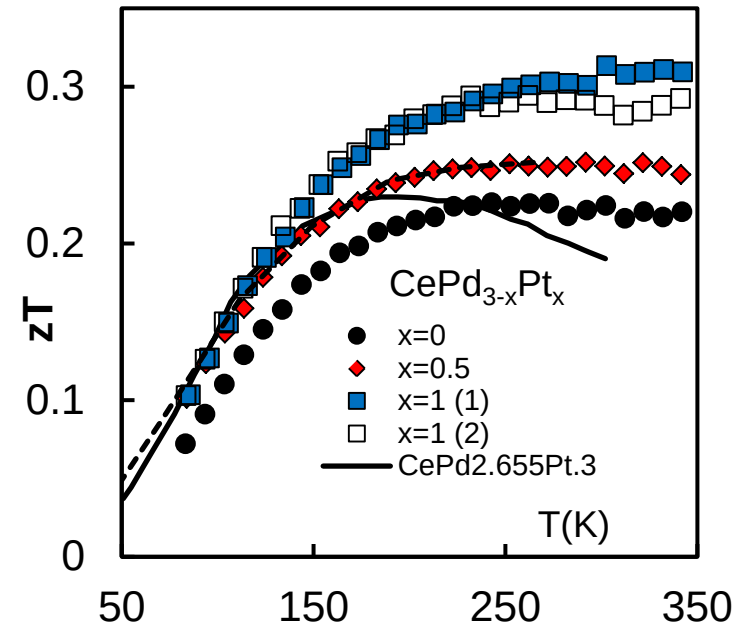
n-type material: $\text{Bi}_{93}\text{Sb}_7\text{:K}$



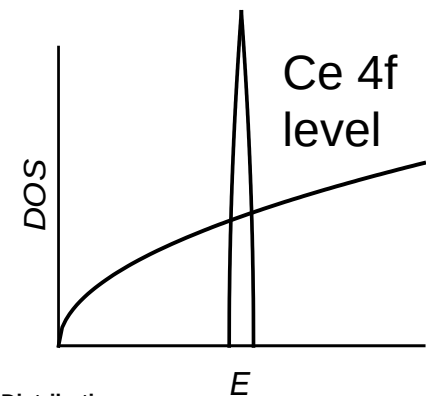
Principle:
K is a
resonant level
in BiSb



p-type material: CePd_2Pt



Principle:
Tune E_F in the
Ce - 4f level



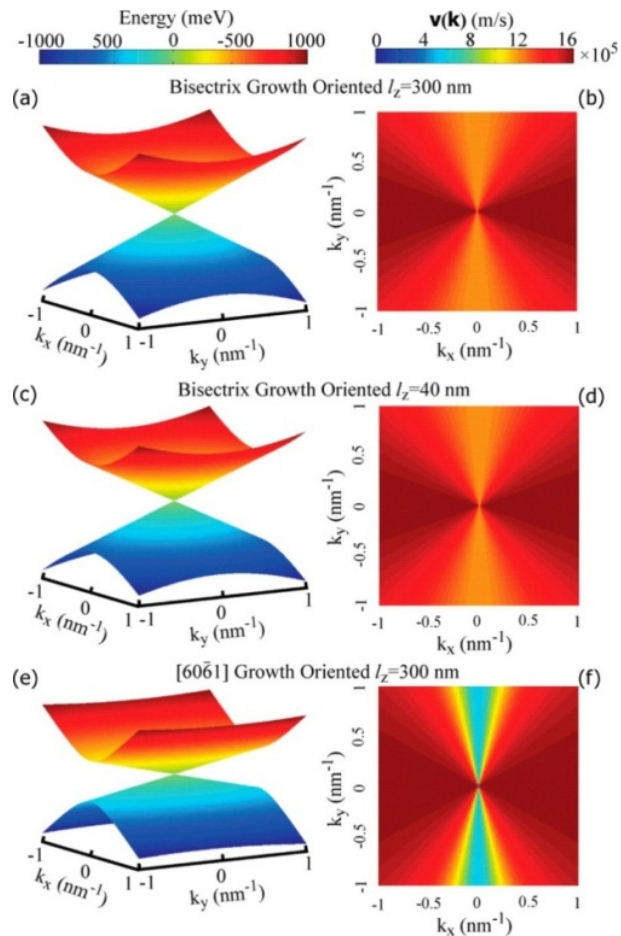


Dirac cones in BiSb and Electron Cloaking

M. S. Dresselhaus and Gang Chen, MIT



Dirac dispersion relations in BiSb alloy thin films



Modulation doping with impurities in core-shell nanoparticles
Nanoparticles invisible to free electrons

