Flexible Electronics

Dr. John Pellegrino

Sensors and Electron Devices Directorate
U.S. Army Research Laboratory

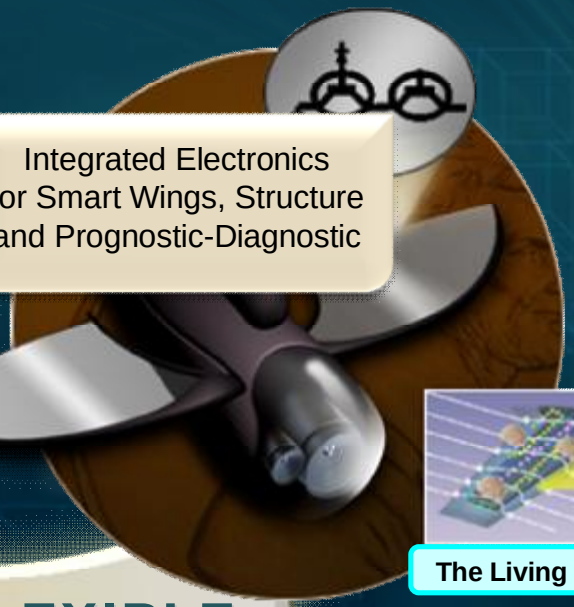
RDECOM

ARL

Approved for Public Release

Future Flexible Electronics
Defense and Security Applications

Fully Flexible Circuit Boards and Packaging



Integrated Electronics for Smart Wings, Structure and Prognostic-Diagnostic

The Living Airframe

Nano-Biomotor Devices: Possible DNA Detection

FUTURE FLEXIBLE ELECTRONICS

Flexible Digital Radiology

- **Health Monitoring Stress - fatigue**
- **Flexible Blast Dosimeters**
- **Chemical Biological Radiation Sensors**

Soldier Health and Environmental Monitoring

Distributed Multi-Functional Sensors

Future Flexible Electronics
Defense and Security Applications

Decision Support

Situational Awareness

IMPACT ON THE SOLDIER

Medical

Prognostic &
Diagnostic

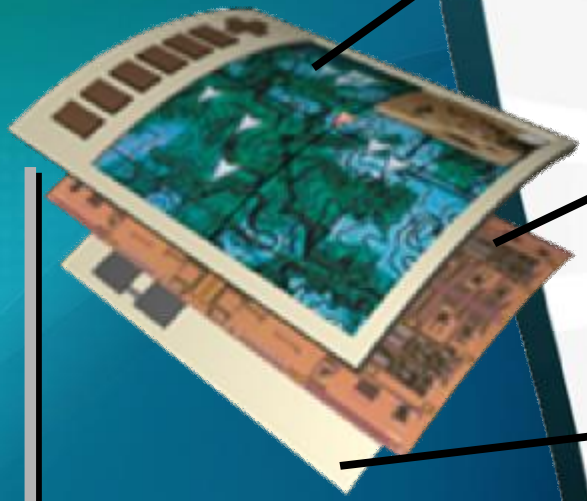
Future Flexible Electronics
Defense and Security Applications

Future Flexible Electronics
Flexible Electronic Systems

Defense Electronics
Consumer Electronics

Today's Army Hardware

Light-weight, rugged concepts



Flexible Display Component

Flexible Circuit Boards

Power

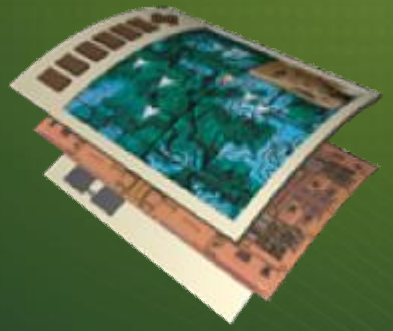
Flexible Interconnects and Packaging

US ARMY RDECOM

Future Flexible Electronics
Medical Applications

Defense Electronics
Soldier Health Monitoring
Environmental Monitoring

Structural Monitoring



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Medical Imaging and Diagnostics

Medical Sensors

PENNSTATE

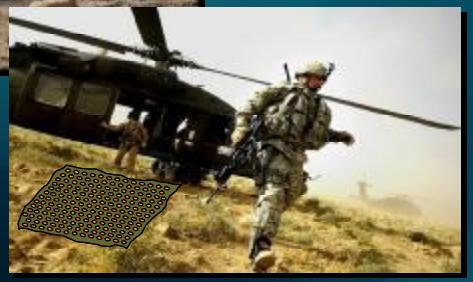
Increasing Functionality

Flexible Displays, Electronics, Sensors

Future Flexible Electronics
Distributed Sensor Arrays

Large Area, Rugged
Sensor Arrays and Grids
Decision Support

Today's Army Hardware



Battery

Energy Harvest-Storage

Solar, Battery, Super Capacitors

Circuit Boards

Flexible Electronics

Power management, distribution, Communications

Antenna

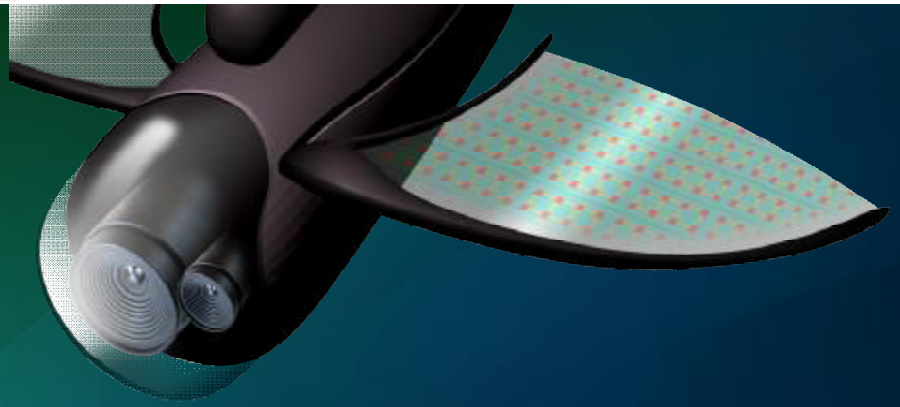
Communication Signals

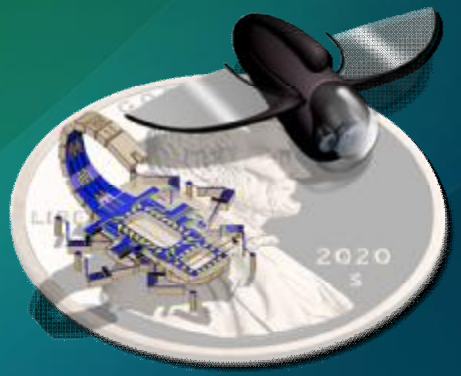
Flexible antennas

Large Area Sensors, Lighting

Future Flexible Electronics
Micro-robots: *Electronics &Sensors*

Defense Electronics
Light Weight Sensors
Conformal Electronics





Today's Army Hardware

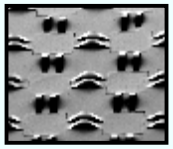
SEDD Technology Investment Area
Micro Autonomous Systems and Technology

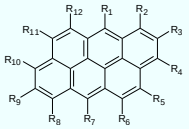
Future Flexible Electronics
Building Blocks

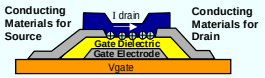
Focused, Coordinated Program Integrating the Building Blocks to Realize an Industry

MATERIALS AND DEVICES

Organic, Mixed oxides TFTs
Analog, Digital, Hybrid Si CMOS

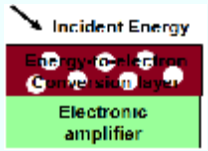


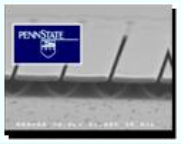




IMAGING ARRAYS AND SENSOR

Hybrid-organic nano-particle
Bio-compatible materials

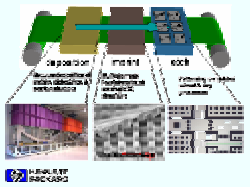


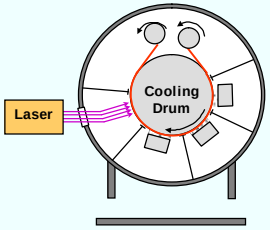


ENERGY HARVESTING AND STORAGE

Flex-PV
Super Cap
Thin Battery

MANUFACTURING & PACKAGING





Multi-scale Modeling and Simulation

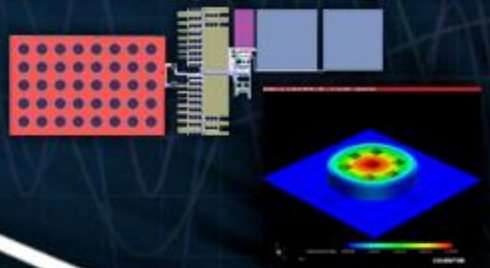
TFT Simulators
Sensor+TFT
simulators

Future Flexible Electronics
Early Technology Demonstrators

US ARMY RDECOM

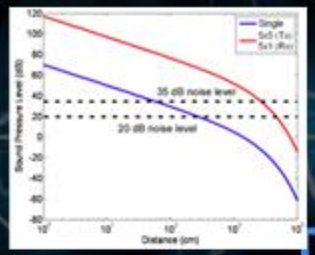
ARL

Blast dosimeter arrays elements to measure multiple frequencies

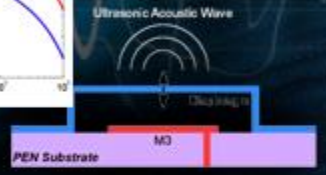


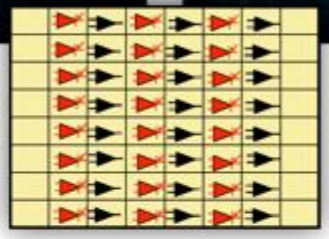
Army Medical Program

Acoustic transmitter array
Covert communications
up to 50m

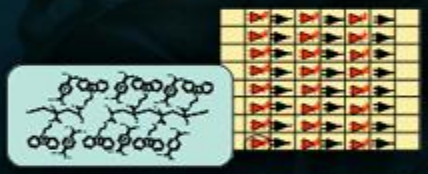


ARL Coop Agreement





Large Area Distributed Electronics

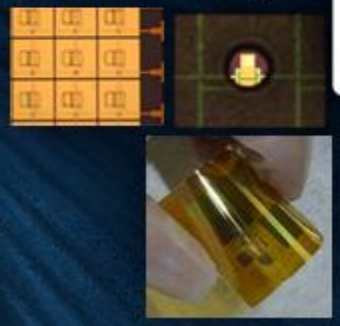


Organic medical Sensor arrays

Flex-Si CMOS

Flexible Displays

Neutron/gamma Detectors,
XRAY, IR large area
High sensitivity



PENNSTATE

ARL Program Manager

(2) ARL SBIRs

Strategic Partnership: Army's Flexible Display Program

Flexible Display Center at Arizona State University

ASU Flexible Display Center
ARIZONA STATE UNIVERSITY

US ARMY RDECOM

28 Industry Partners

Display Industry | **Military LSIs**

Emissive OLEDs

Reflective Electrophoretic

(9) SBIR Programs

FlexTech Alliance & Industry **Funded Programs**

PEO – PMs – FCS
Army Technology Transition Agreements

TRADOC Schools
Army Requirements

Academic Centers

Center for **A**dvanced **M**icroelectronics **M**anufacturing
SIP CAMM

University Programs

FlexTech Alliance | ARL Funding

Strategic Partnership: Developing Flexible Electronics

Government Agency Partners

US ARMY RDECOM

Flexible Display Center at Arizona State University

ASU Flexible Display Center
ARIZONA STATE UNIVERSITY

Central-Focus for Integration

Self-formed Industry Teams and Funding

28 Industry Partners

Display Industry | Military LSIs

(9) SBIR Programs

FlexTech Alliance & Industry Funded Programs

Well Defined Demonstrator Roadmap

Developing Customer-pull Technology Transition

PEO – PMs – FCS
Army Technology Transition Agreements

TRADOC Schools
Army Requirements

University-led Innovative Basic RD

Academic Centers

Center for Advanced Microelectronics Manufacturing

SIP CAMM

University Programs

FlexTech Alliance | ARL Funding

Future Flexible Electronics Manufacturing Considerations

Current High-Tech Manufacturing (CMOS, Displays);

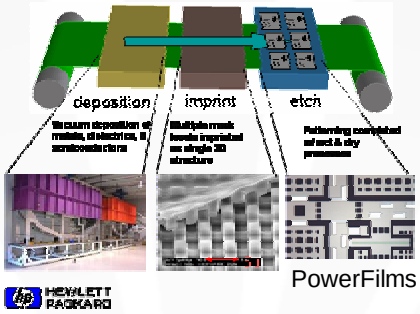
- Highly optimized; low-profit margin
- "*Restoring American Competitiveness*" G. Pisano & W. Shih

Flexible Electronics Manufacturing;

FlexTech Alliance *ARL Coop Agreement*

- Applications with potential for high-profit margins
- Leverage optimized CMOS/display manufacturing (bond-debond)
- Imprint lithography in roll-to-roll

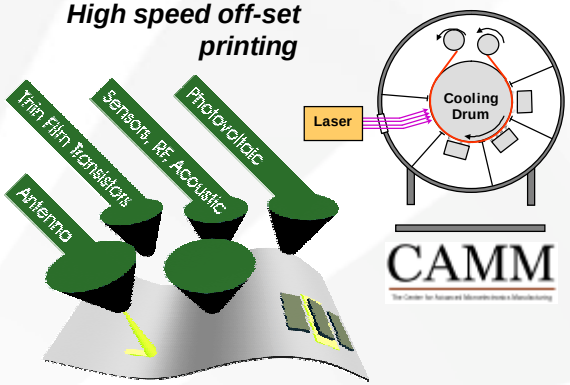
Plate-to-plate processing
ARL Cooperative Agreement
Flexible Display Center



PowerFilms

Imprint Lithography
ARL Cooperative Agreement

High speed off-set printing



Printing-R2R
ARL Cooperative Agreements
Honeywell, HP,
Plextronics, CAMM

Emerging Flexible Electronics

Medical Imaging and Diagnostics

- Emerging Flexible Electronics: *Displays, Electronics, Sensors, Energy*
- New concepts for Security and Defense:
  - Decision Support
  - Medical Monitoring
  - Distributed Sensors
  - Micro-Robots
- Enabling Large-Area, Rugged Novel Form-factor Applications

NIST and the Technology Innovation Program

An Early Investor in Flexible Electronics

Flexible Electronics for Security, Manufacturing, and Growth in the United States

The National Academies

September 24, 2010

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Senior Scientific Advisor to the Director
Technology Innovation Program
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NIST National Institute of Standards and Technology U.S. Department of Commerce

TIP Technology Innovation Program

NIST Mission and Programs

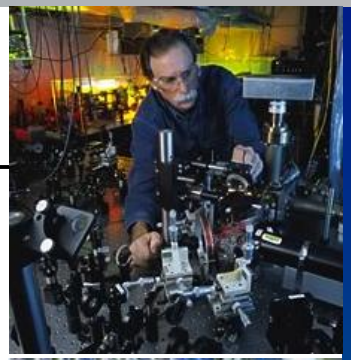
To promote U.S. innovation and industrial competitiveness by advancing

- measurement science,
- standards, and
- technology

in ways that enhance economic security and improve our quality of life

Major Programs

- NIST Laboratories
- Baldrige National Quality Program
- Manufacturing Extension Partnership
- Technology Innovation Program


© Geoffrey Wheeler


Courtesy Stoner Inc.


Courtesy Steuben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NIST Provides Innovation Infrastructure

The "roads and bridges" of research that industrial and scientific communities need to develop and commercialize new technologies

- **Groundbreaking research tools that foster new fields**
- **Performance measures for accurate technology comparisons**
- **Standards to assure fairness in trade**
- **Public-private partnerships to accelerate technology**

Why Flexible / Printed Electronics and NIST?

- Demonstrated sustainable industry leadership
- A unique need for advancements in measurements and standards tools
- Requires high-risk manufacturing innovation for which private capital is not readily available
- A realizable opportunity to:
  - Generate new U.S. jobs in advanced materials, equipment, and a new generation of electronics manufacturing
  - Address a variety of critical national needs including energy efficiency and generation, national security, and healthcare
  - Compete globally

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Credit: Orandi, NIST

Flexible / Printable Electronics at NIST

- Laboratory metrology programs in materials, structure, processing and electronics
- Technology Innovation Program (TIP) funding in Manufacturing
  - Advanced materials scale-up in the 2009 and 2010 competitions
  - Critical process advances in 2010
- White papers by industry stakeholders
  - Societal challenges and technical gaps in flexible / printable electronics and impact areas

NIST's Toolkit for Transformative Innovation

Technological Readiness	NIST Programs and Actions
Discovery / Proof of Principle •Peer-reviewed journal articles •Intellectual property	***NIST Laboratories*** ***Construction Grant Program*** • World-class measurements and science • High impact publications • New research science facilities
Early Stage Innovation / Consortia •Materials and Prototype Research •Manufacturing Research •FlexTech Alliance •SEMATECH, NEMA -NGLIA	***NIST Laboratories*** ***Technology Innovation Program (and the former Advanced Technology Program)*** • Multidisciplinary programs • Public-Private Partnerships • Alignment with roadmaps
Rapid growth of an industry •Industry-wide standard practices •Transition to high-volume manufacturing •Pervasive integration across industries	***NIST Laboratories*** ***Technology Innovation Program*** ***Standards Services*** • Measurement solutions; Tech transfer • Public-Private Partnerships • Lead standards development
Mature industry •Greater focus on efficiency •Integrated network of stakeholders	***Manufacturing Extension Partnership*** ***Standards Services*** • Standards and standard practices • Calibrations services

A Technology and Market Snapshot: *Large Area, Flexibility, and Function*

- Printed, organic, flexible electronics, including printing, electronics, materials and packaging → Pursued by over 3,000 organizations globally
- Market estimate for printed and thin film electronics → $ 1.9 Billion in 2010, $55.1 Billion by 2020
- Now predominately OLED / e-paper displays and photovoltaics. Soon thin film transistor circuits, sensors and batteries → 35% printed in 2010, and by 2020, 71% printed and 60% on flexible substrates

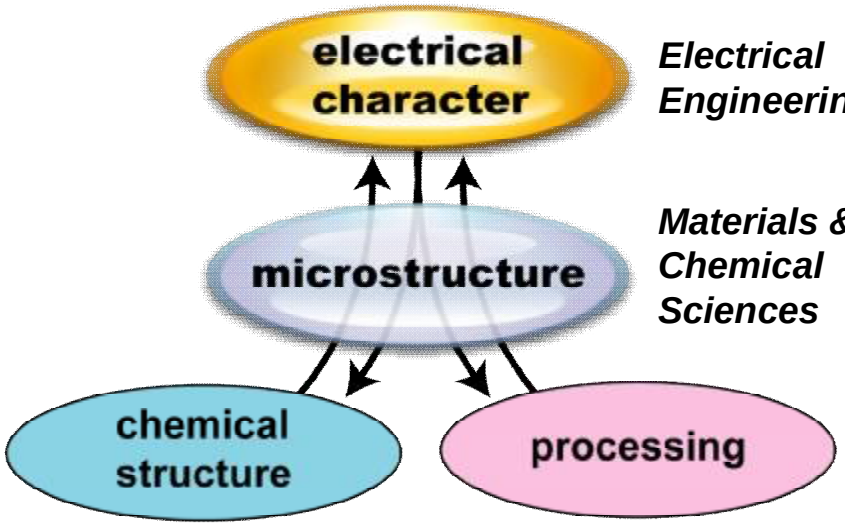
IDTechEx, ***Printed, Organic & Flexible Electronics Forecasts, Players & Opportunities 2010-2020, 2010.***

Flexible and Printable Electronics are Poised to Have a Global, Disruptive and Transformational Impact

NIST Laboratories Flexible Electronics Program

Metrology to Enable the Realization of Flexible Electronics

- To "*provide the integrated measurement and standards tools needed to accelerate progress in flexible electronics*"
- Meets needs expressed by flexible electronics technology developers



Electrical Engineering

Materials & Chemical Sciences

...via collaboration and in-house

Collaborations

Stanford University
Carnegie Mellon
PENNSTATE
Berkeley
H.C.Starck
parc
VITEX SYSTEMS
Imperial College London
UCSB
Seoul National University
University of Maryland
Queen Mary University of London
XEROX
IBM
PLEXTRONICS
ASU Arizona State University
MIT Massachusetts Institute of Technology
University of Kentucky
Northwestern University
MERCK
IPC
CORNING

NIST Public Private Partnerships: *Innovation Accelerants in Flexible / Printable Electronics*

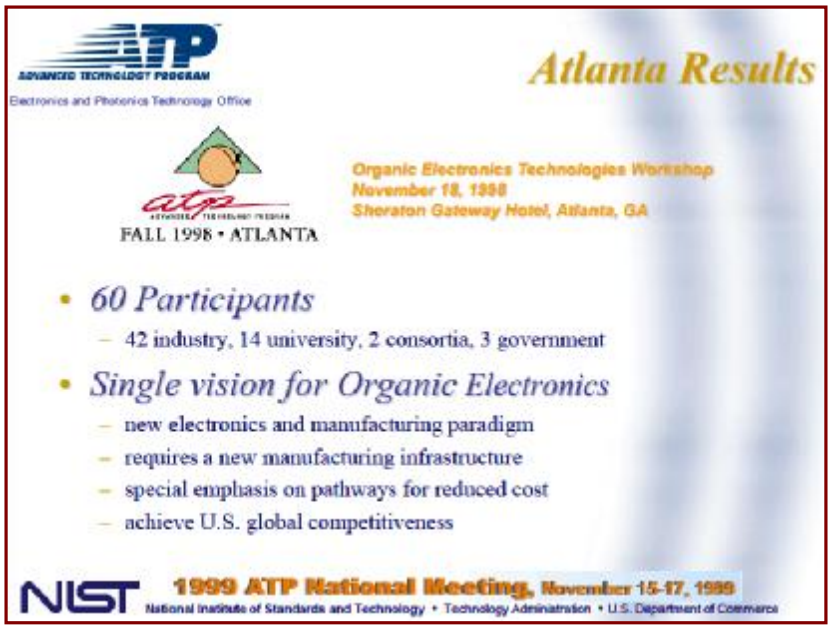
- Former *Advanced Technology Program (ATP)* – an early funder
  - Funded Flexible Electronics projects from 2000 to 2007
    - Primarily vertically structured consortia
    - Focused principally on manufacturing prototyping and prototype systems innovation research

- Today's *Technology Innovation Program*
  - 2009 Competition: *Accelerating the Incorporation of Materials Advances into Manufacturing Processes*
    - Awards in scale-up and manufacturing research for advanced functional inks and next generation electronic materials
  - 2010 Competition: *Manufacturing and Biomanufacturing: Materials Advances and Critical Processes*
    - *Proposals under evaluation, announcements in Fall 2010*

Early Dialog in Flexible / Printable Electronics: *1998 and 1999 ATP Workshops*

Array of Functionality

- Conducting / Semiconducting
- Light Emitting / Transmitting
- Detecting / Sensing



Potential Applications

- Displays
- Optical Interconnection
- Disposable Electronics
- Lighting
- Electronics Manufacturing

What's Needed

- Manufacturing Processes and Equipment Infrastructure
- Improved Materials and Device Compatibility, Reliability and Performance
- Application-driven, Vertically Integrated Teams

ATP's Contribution *(2000 to 2007)*

Predominately vertically aligned, multi-party Joint Ventures

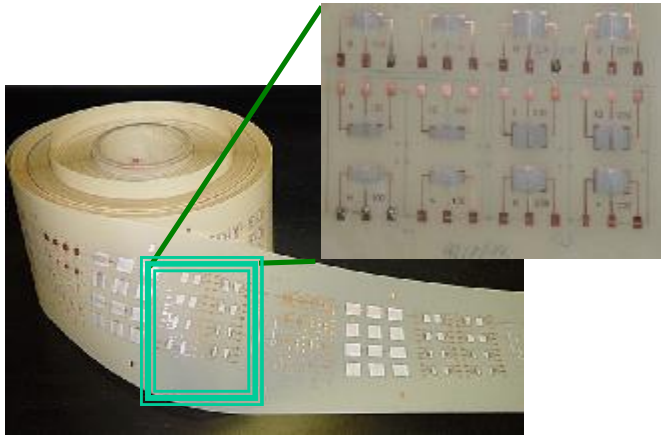
- Key objectives
  - Demonstrate the viability of various manufacturing approaches for flexible / printed circuits
  - Further electronic devices and materials development
  - Help create an early flexible / printable electronics capability
- Market drivers
  - Electronic displays, signage and circuits
  - OLED solid state lighting
  - Thin film PV

Early funding of carbon nanotube printable electronic inks

Flexible / Printed Circuits

Printed Organic ASICs: A Disruptive Technology

Motorola, Inc. / Dow Chemical Co. / Xerox XRCC / Xerox PARC
2000 to 2004

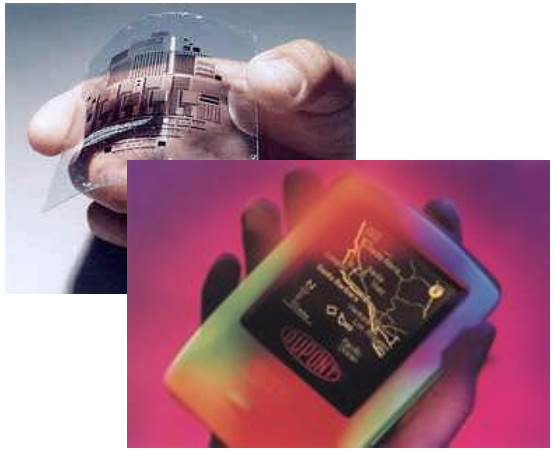


Develop novel organic electronic materials and processing technologies for the fabrication of ASIC's using relatively inexpensive printing technologies in lieu of semiconductor lithography.

Printed Organic Transistors on Plastic for Electronic Displays and Circuits

Sarnoff Corp. / DuPont / Lucent Technologies
2002 to 2005

Develop and demonstrate printable organic electronic materials and fabrication technologies for low-cost, high-volume production of thin film transistors (TFTs) and displays.



Solid State Lighting and Thin Film Photovoltaics

Roll-to-Roll Processing to Enable the Organic-Electronics Revolution

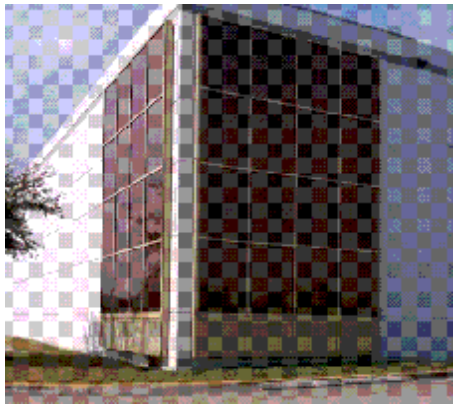
GE Global Research / Energy Conversion Devices, Inc.
2003 to 2007

Revolutionize the electronics industry by developing low-cost roll-to-roll printing technologies for manufacturing large area organic electronic devices.

Transparent, Flexible Solar Modules Based on Bulk-Heterojunction Organic Photovoltaic Technology

Konarka Technologies / Cambridge Major Laboratories
2008 to 2013

Develop high-performance, transparent photovoltaic cells and modules that will help establish solar technology as a vital part of the renewable energy industry.



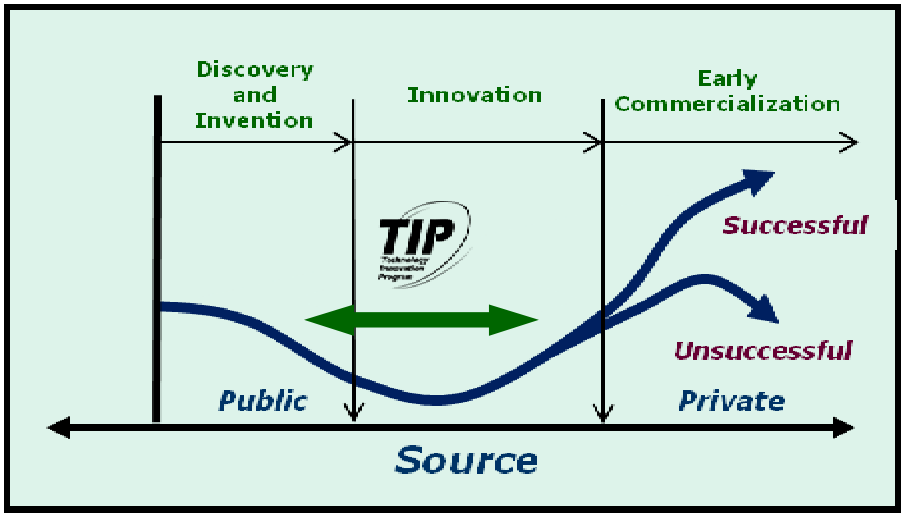
The Technology Innovation Program

Funding Transformational Research for Critical National Needs

www.nist.gov/tip

TIP's Mission

- Assist United States businesses and institutions of higher education or other organizations, such as national laboratories and nonprofit research institutions
- Support, promote, and accelerate innovation in the United States through high-risk, high-reward research
- In areas of critical national need



America COMPETES Act, (PL 110-69)
August 9, 2007

Characteristics of TIP

Novel Purpose

- Address societal challenges not being addressed in areas of critical national need with benefits that extend significantly beyond proposers

Scientific & Technical Merit

- Fund High-risk, high-reward research

Transformational Results

- Select projects with a strong potential for advancing state-of-the-art and contributing to U.S. science and technology base

Rich Teaming

- Fund small- and medium-sized businesses, academia, national labs, nonprofit research institutions other organizations
- Large companies may participate in the project research but cannot receive government funding

TIP is an **AGENT FOR THE ACCELERATION OF TECHNOLOGY INNOVATION,** spurring the translation of discovery research with transformational potential into U.S. industry, through high-risk, high-reward innovation research

Current TIP Critical National Need and Interest Areas

Critical National Need Areas

- Civil Infrastructure*
- Manufacturing*

Other Interest Areas

- Advanced Robotics
- Complex Networks
- Energy*
- Healthcare*
- Sustainability
- Water

Interest Areas subject to change as TIP focuses on the Nation's most pressing priorities!

*** TIP White Paper available for public comment**

2009 TIP Awards in Manufacturing: *Flexible / Printable Electronics*

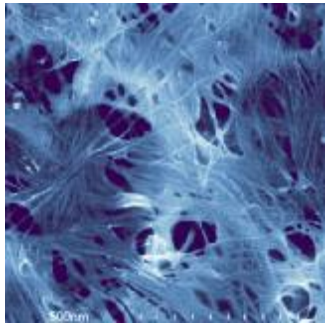
Goals

- *Accelerate the availability of advanced materials for tomorrow's manufacturers*
- *Scale-up and modeling to support integration*

Production of Low-Cost, High-Quality Metallic and Semiconducting Single Wall Carbon Nanotube Inks

Brewer Science, Inc. / Southwest Nanotechnologies, Inc. (2010 to 2013)

Develop technologies for the cost-effective production of high-purity, high-quality, metallic and semiconducting carbon nanotube 'inks' to enable commercial production of a wide variety of high-performing electronic devices for energy, flexible electronic and sensor applications.



Chastek/Talbott/NIST

Functionalized Nano Graphine for Next-Generation Nano-Enhanced Products

Angstron Materials, LLC (2010 to 2013)

Develop processes for mass-producing chemically modified ("functionalized") nano graphene for next-generation products, particularly for the energy industries.

How TIP, NIST and Flexible / Printable Electronics Intersect Today

A Rapidly Evolving Landscape

Early stage commercialization is underway

Represents a set of platform technologies that will enable a cost effective heterogeneous integration of functionality – e.g. circuits, sensing, display, energy generation, and beyond - within products

Industry participation and leadership exists, but can be expanded

- TIP white papers and proposals
- NIST Metrology research collaborations
- Pursuit of domestic and international standards

How TIP, NIST and Flexible / Printable Electronics Intersect Today (cont.'d)

Nanomanufacturing matters!

- Scale-up and commercialization of functional materials and inks are leveraging early U.S. nanotechnology investments
- May become a differentiator that enables high performance products and opens new markets

TIP is being used to accelerate supply chain innovation

NIST-wide advancements in measurement tools and standards for characterization, device development, and manufacture and control remain essential

NIST's Construction Grant Program (est. 2008)

For Tomorrow's Research Science Buildings

Program Goals and Objectives

- To provide competitively awarded grants for the construction of new, or expansion of existing, *research science buildings*
- Grants awarded to U. S. institutions of higher education and non-profit organizations for research facilities performing all applicable fields of science that complement NIST, NOAA, and/or NTIA programs

Artist rendering of the planned new Brockman Hall for Physics at Rice University. Courtesy of Rice University

Awards to Date

- November 2008: Three awards, $24 million
- July 2009: Four awards, $55.5 million
- January 2010: Twelve Awards, $123 million
- Fall 2010: soon to be announced

Proposed center for Applied Energy Research Laboratory Expansion, University of Kentucky. Artist's rendering provided by BHDP Architecture

(www.nist.gov/director/ncgp)

NIST's Priorities: *A Roadmap for Aligning Partnerships in Flexible / Printable Electronics*

Strengthen and focus NIST's Laboratories and facilities to ensure U.S. leadership in measurement science and standards

- Improve NIST measurement and standards services
- Enhance the facilities and equipment that enable cutting-edge research
- Promote leadership at the frontiers of science and technology

Focus new NIST activities to address critical national priorities

- Energy
- Environment
- Healthcare
- Information Tech.
- Manufacturing
- Physical Infrastructure

Promote partnership mechanisms with industry and academia through extramural programs

- Technology Innovation Program
- Hollings Manufacturing Extension Partnership
- Baldrige National Quality Program

Expand collaboration to leverage NIST capabilities and advance innovation at regional and national levels

Concluding Thoughts: *What Flexible / Printable Electronics Means to the U.S.*

New high tech entrepreneurs, small businesses, and jobs are taki ng hold

- An new supply chain and manufacturing infrastructure
- Commercializers of advanced materials, inks, process technologies, and devices
- Offering novel products and innovation in critical national needs like national security, energy and healthcare

State and regional initiatives in are underway to spur regional economic growth, innovation and commercialization

Improving the efficiency of innovation and translational research
- within the private sector and between public and private sectors -
will accelerate U.S. job creation and strengthen U.S. global competitiveness in the field

Partnerships are key!

Thank you

Questions?