QUERREY SIMPSON INSTITUTE FOR BIOELECTRONICS

Northwestern

From Scientific Discovery to Engineering Development and Commercial Deployment

Three Short Stories: *From the Lab to the Real World*

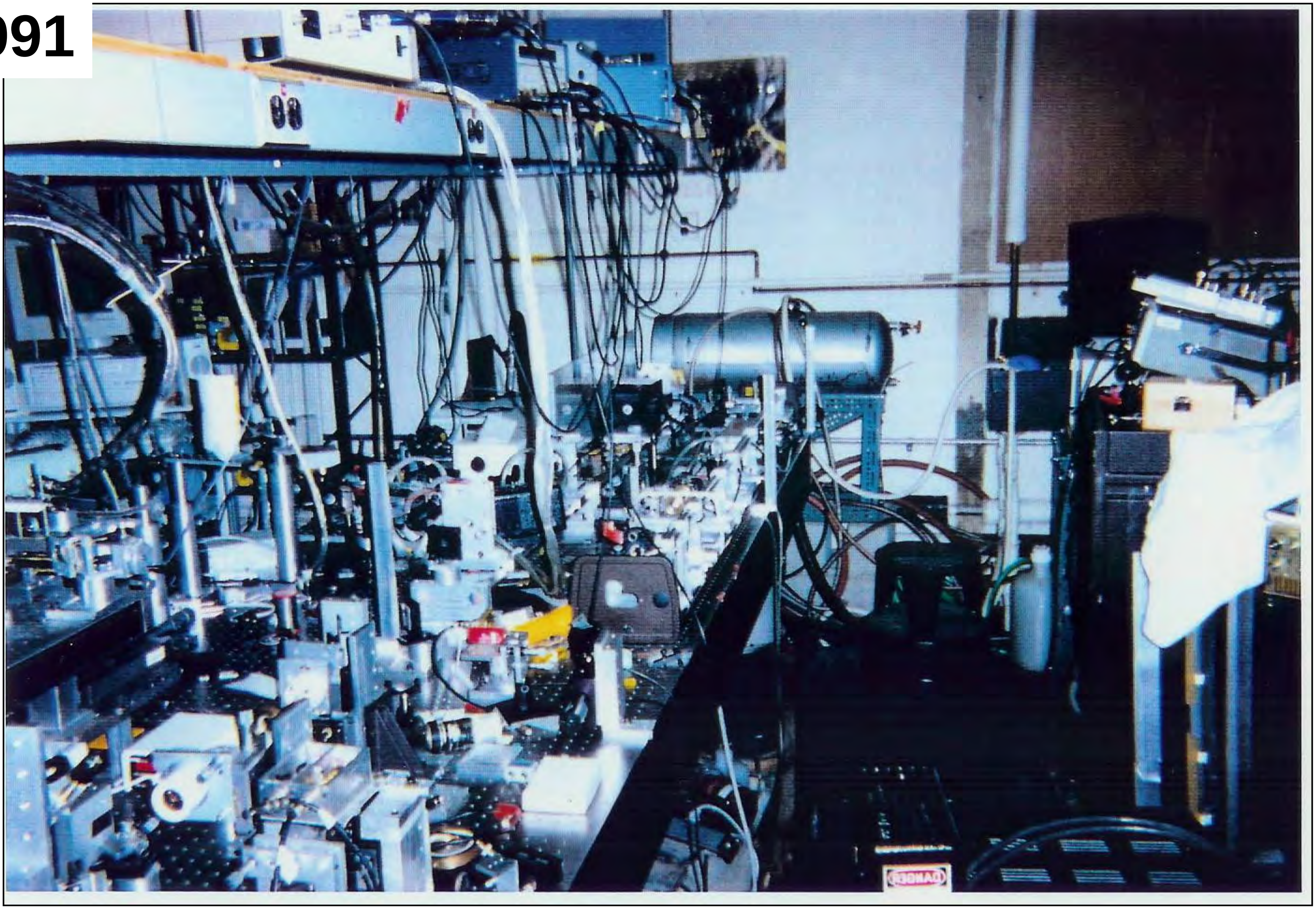
1) **MIT – *Semiconductor Metrology***

2) **Bell Laboratories – *Lightwave Communications***

3) **Northwestern University – *Health Technology***

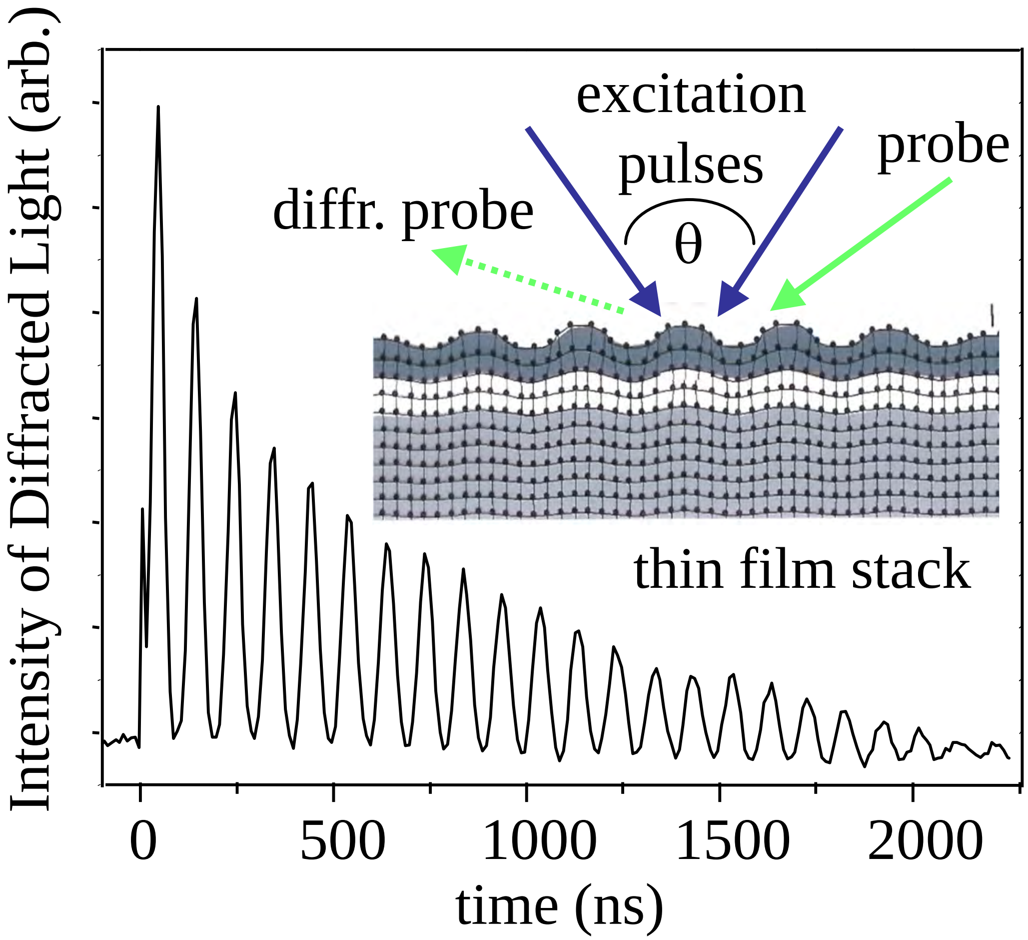
PhD Research on Picosecond/Femtosecond Lasers

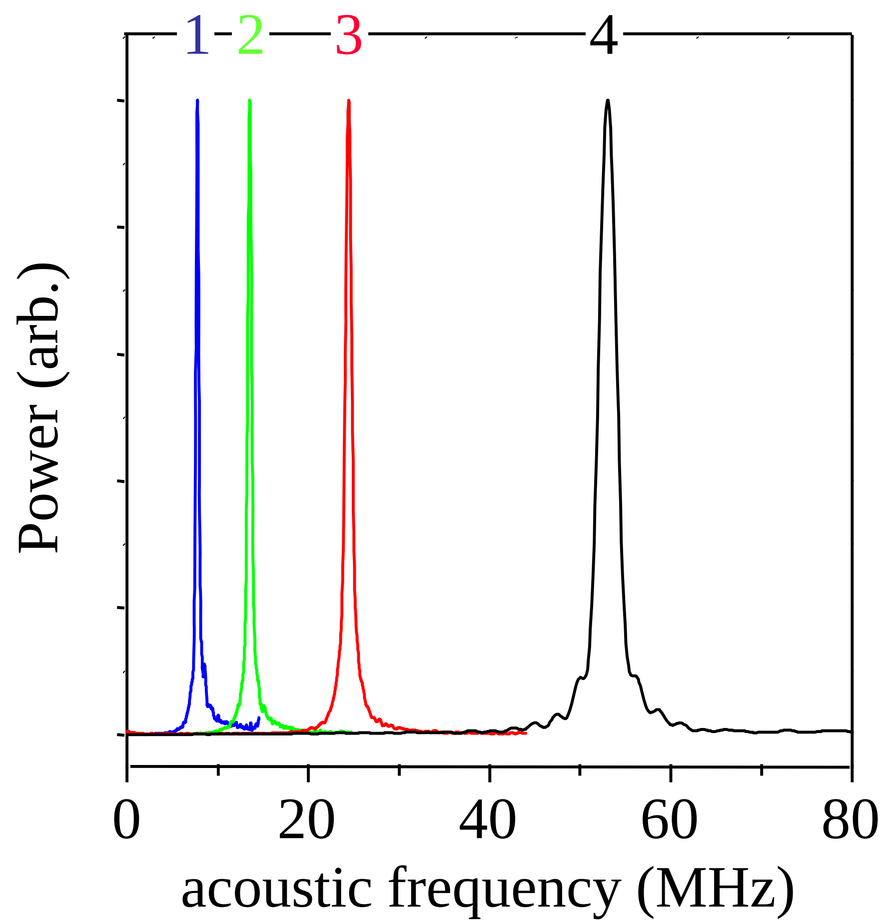
1991



Picosecond Thin Film Ultrasonics

Supported by the Electronics Packaging Program





1992

Massachusetts Institute of Technology

Active Impulse Systems – 10K Business Plan Comp

1995

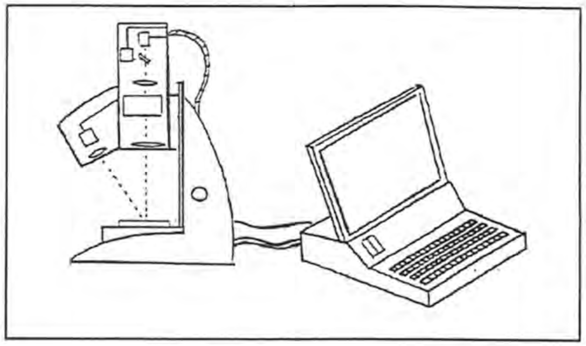


Figure 4. A schematic illustration of the ISS-AII film-measuring device.

4. Materials Characterization Services

Based on our research and development experiences, we recognize the need to establish credibility and to evolve our products to meet market demands. To reach these ends, to adapt to the industry trend toward out-sourcing, to serve smaller companies, and to generate immediate revenue, ISS will offer materials characterization and consulting services. Our marketing research and past experiences indicate that the long-term potential for a service-based effort using ISS's core technology is substantial. ISS will charge the current industry rate (roughly $200 per hour) for measurements; a 20% surcharge will be applied for rush services.

5. Competitive Advantages

ISS devices will compete with more conventional mechanical and thermal testing instrumentation. Current state-of-the-art devices for elastic property evaluation include tensile testers, acoustic microscopes, and nano-indenters, along with a variety of more exotic and less widely accepted devices. While each device has important characteristics -- high spatial resolution for the nano-indenters techniques, simple instrumentation for tensile testers, and rapid image generation capabilities for acoustic microscopes -- none of these devices offer ISS's powerful combination of features. For example, some devices require fabrication of specialized test structures which make direct in-line inspection of sample properties impossible. Other devices involve contacting the sample, thereby eliminating the possibility of applications in microelectronics fabrication facilities where sample contamination is of utmost concern. Table 2 lists capabilities for mechanical property evaluation using ISS devices and other commonly used devices.

THE BOSTON GLOBE • WEDNESDAY, MAY 10, 1995

EMERGING BUSINESS

A REPORT ON NEW ENGLAND'S GROWING COMPAN

MIT $10K Competition down to five finalists

Tonight a university student-turned-entrepreneur will walk away with $10,000.

Under the dome at the Massachusetts Institute of Technology, five finalists in the sixth annual "$10K Competition" – a contest for undergraduate and graduate students to develop real-world products – will each present brief summaries of their business plans.

But unlike previous years when some of the products were more consumer-oriented – such as an automatic transmission for bicycles – four of the five product ideas in the current contest address very specialized industrial needs. Two finalists are proposing products for the semiconductor industry; another pair have ideas for the Internet's World Wide Web; and the fifth has a touch-feedback computer device for designers.

The winner will be announced before the MIT Enterprise Forum, which follows the early-evening presentations.

"The level of competition is particularly high this year," said Renee Buck, who previously entered the competition when she was a student at MIT's Sloan School of Management and is reentering the competition with her husband, Tetsuo Ohara, who will be receiving a doctorate degree in mechanical engineering next month.

This year 45 student teams entered the competition. Last month, judges narrowed the field to a dozen teams, who then prepared full business plans outlining market opportunities, product details and start-up plans.

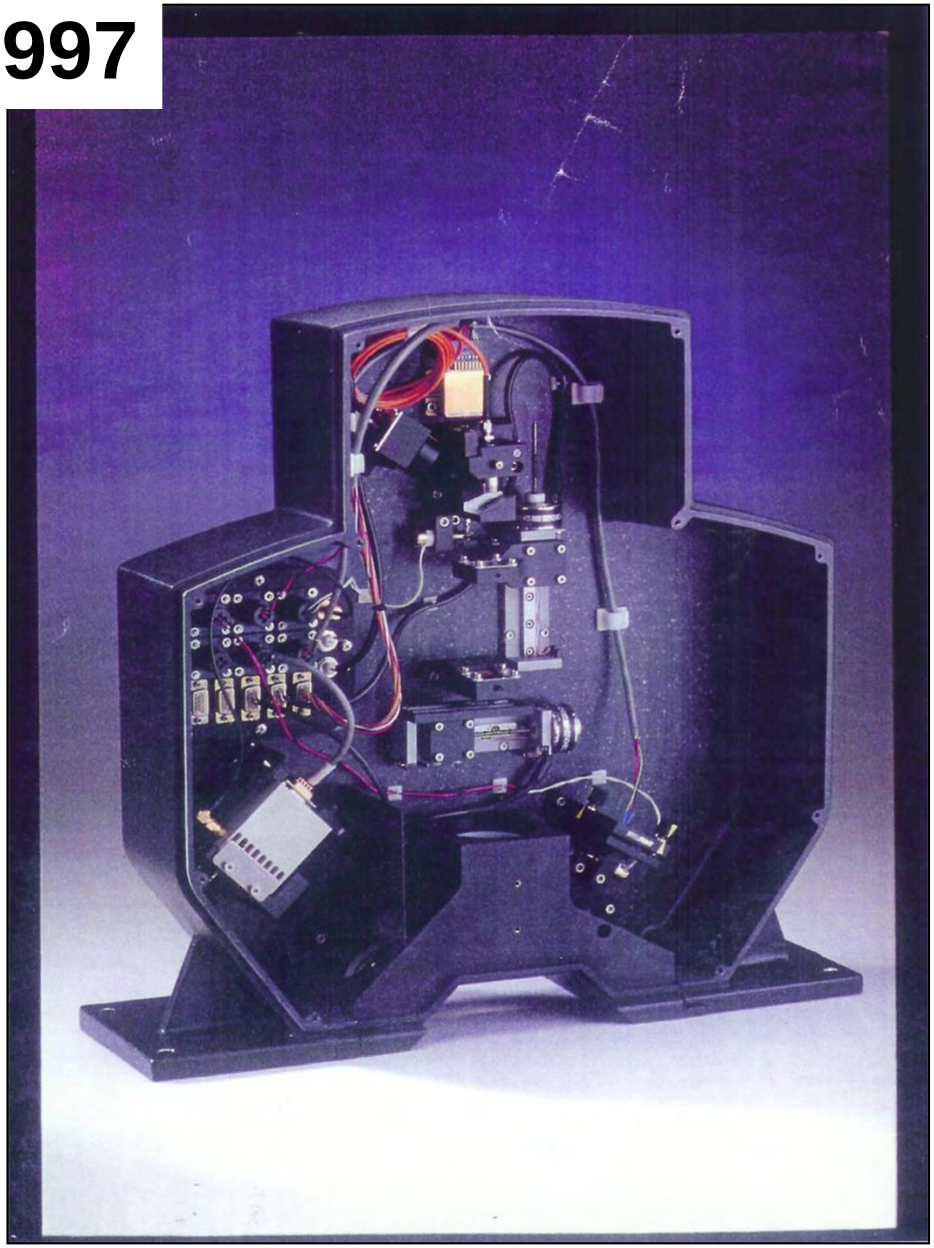
Since then judges from two venture capital firms -- Atlas Venture and Morganthaler Ventures – along with Price Waterhouse, Amen-Data Consulting, Sullivan & Worcester and the MIT Technology Licensing Office chose the following five finalists:

■ Impulse Systems and Services – Looks to help the microelectronics industry quickly measure the stiffness, heat flow and adhesion properties of the various layers of metals and oxide used to create computer chips. ISS has created a laser-based measuring device, according to John Rogers, who conceived the idea and has applied for four patents. He is graduating with a doctorate in chemistry. Rogers said the device, which he expects to cost over $250,000, may also be used in Detroit on automobile assembly lines to help monitor how well new cars are painted.

AIS ACTIVE IMPULSE SYSTEMS

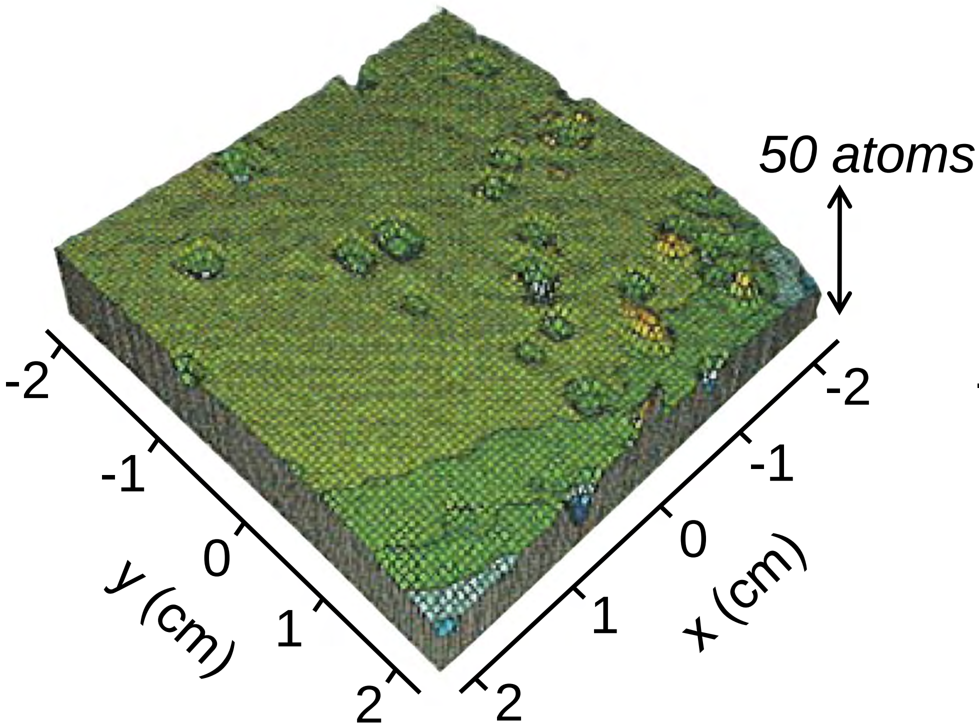
Active Impulse Systems – First Commercial Tool

1997

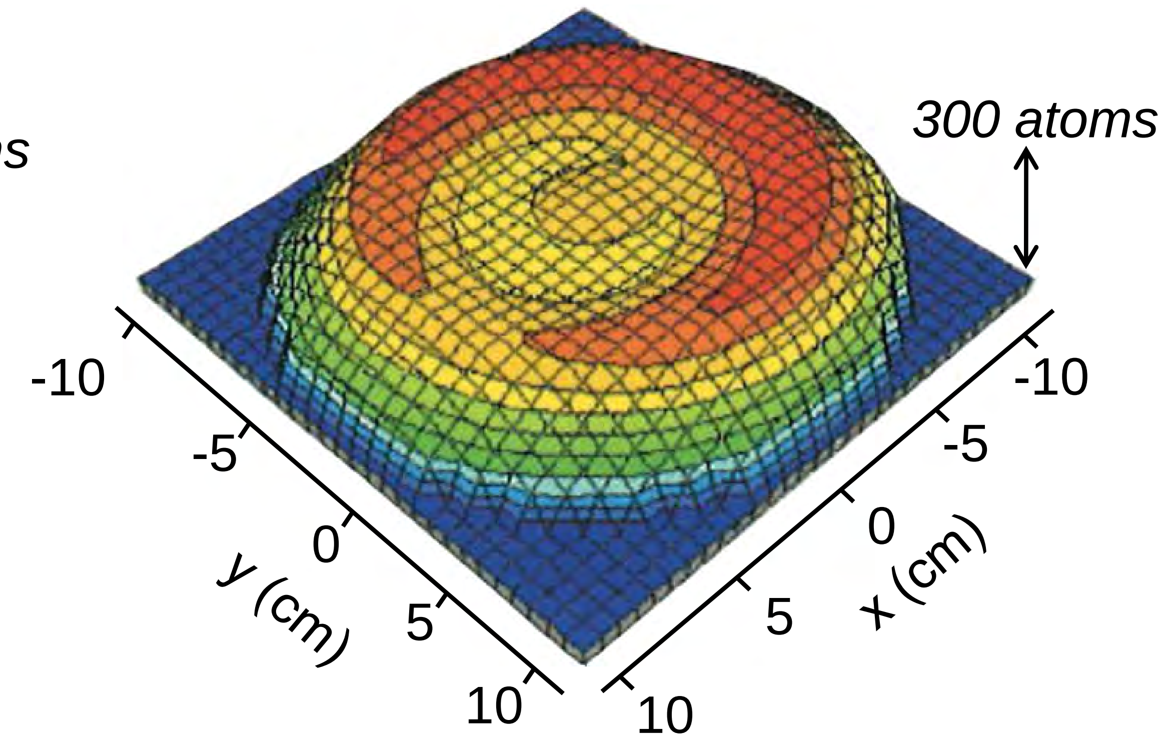


Measuring the Thicknesses of Thin Metal Films

Atomic-Scale Metrology for Semiconductor Manufact.



Fine Resolution



Full Wafer

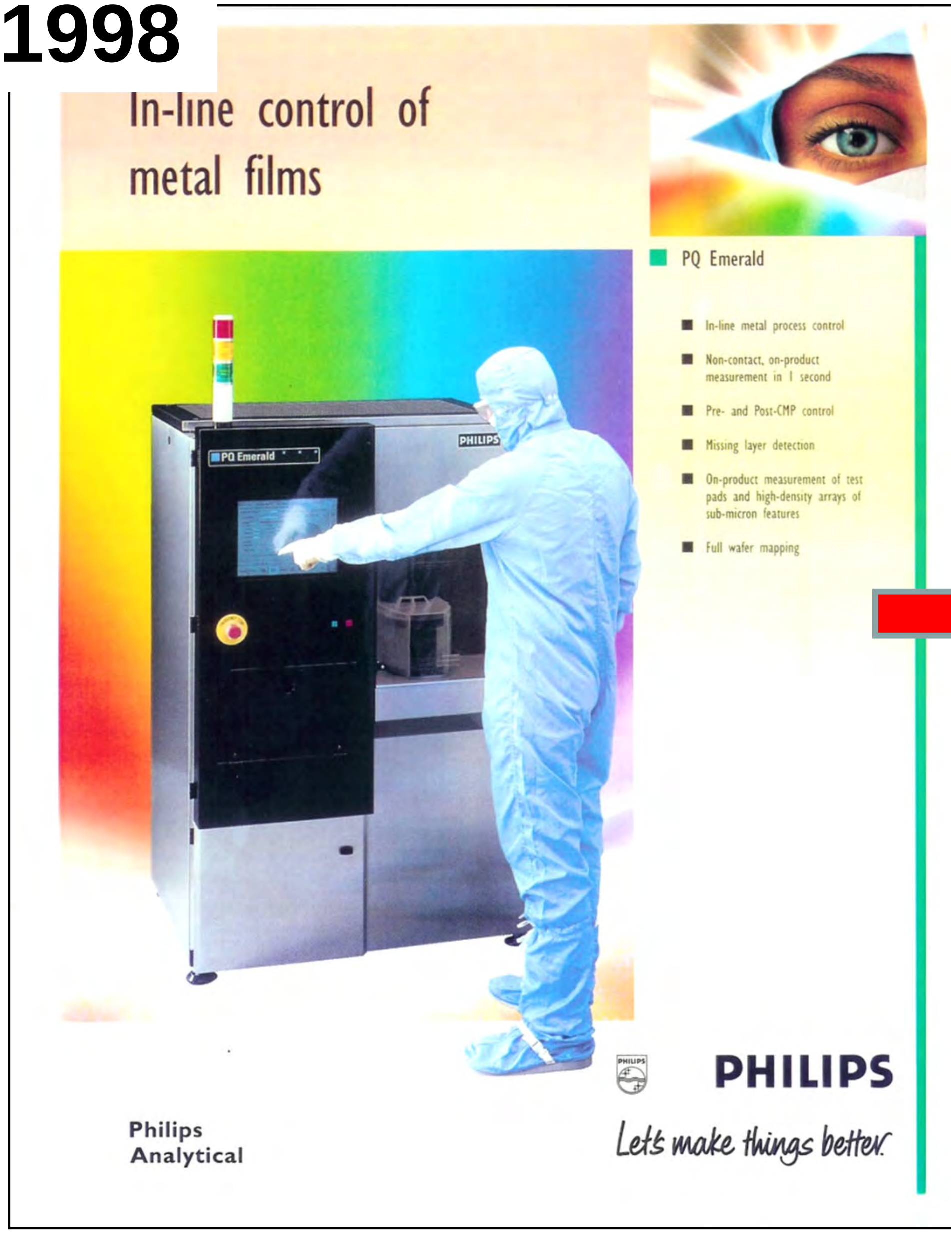
Active Impulse Systems Team; Product Launch

1997

ACTIVE IMPULSE SYSTEMS

Active Impulse Systems / Philips / AMS

1998



2004-

Active Impulse Systems Team; Reunion

2011

Active Impulse Systems, Inc.

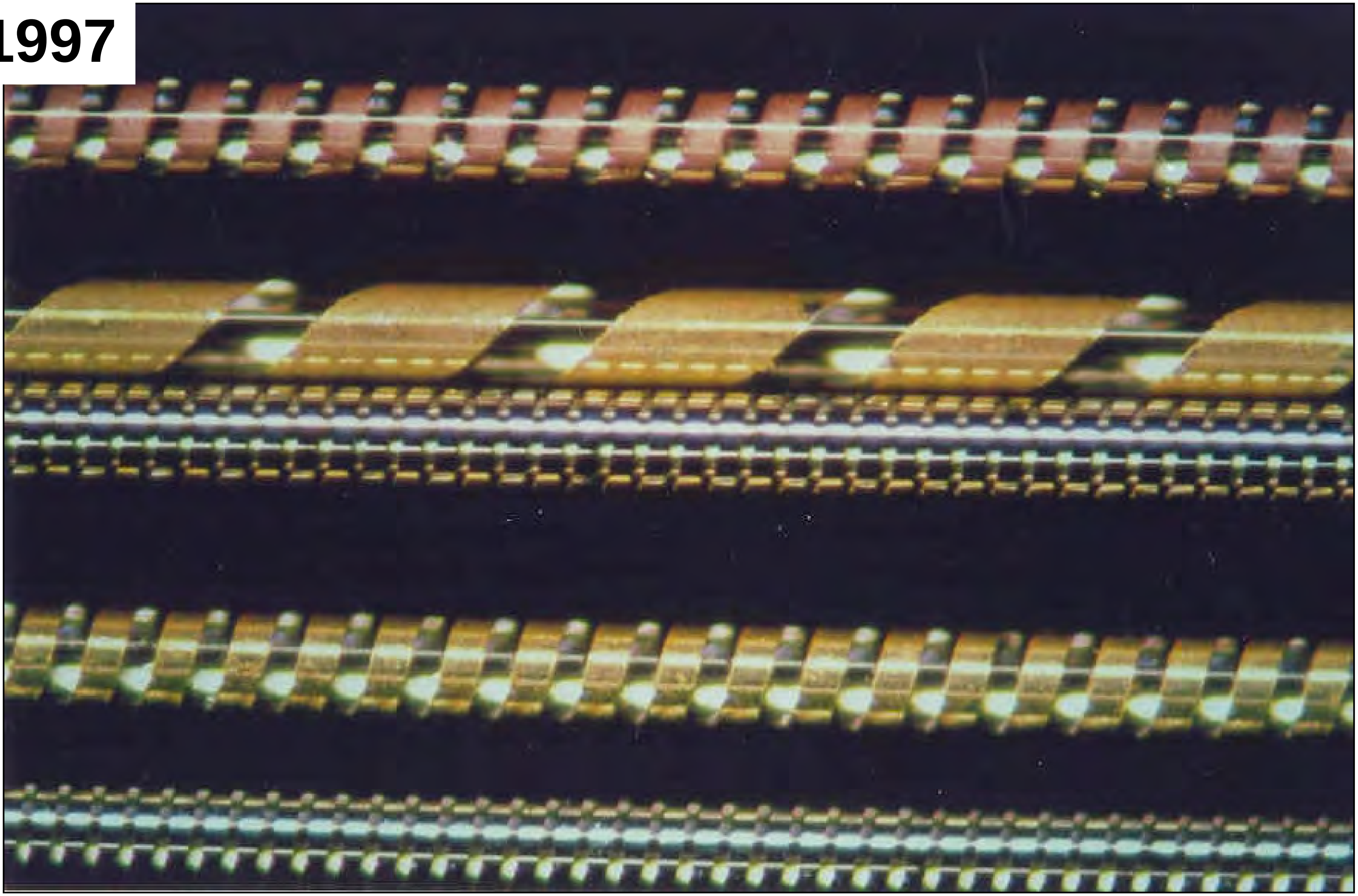
- First paper, patent appl: 1992
- Business plan competition: 1995
- Series A; appl identified: 1995-1996
- Series B; commercial sales: 1997
- Acquisition by Philips: 1998 (Aug. 12th)

6+ years

HARVARD UNIVERSITY

Soft Lithographic Printing: Circuits On Filaments Electronic Cloth, Optical Fiber Devices?

1997

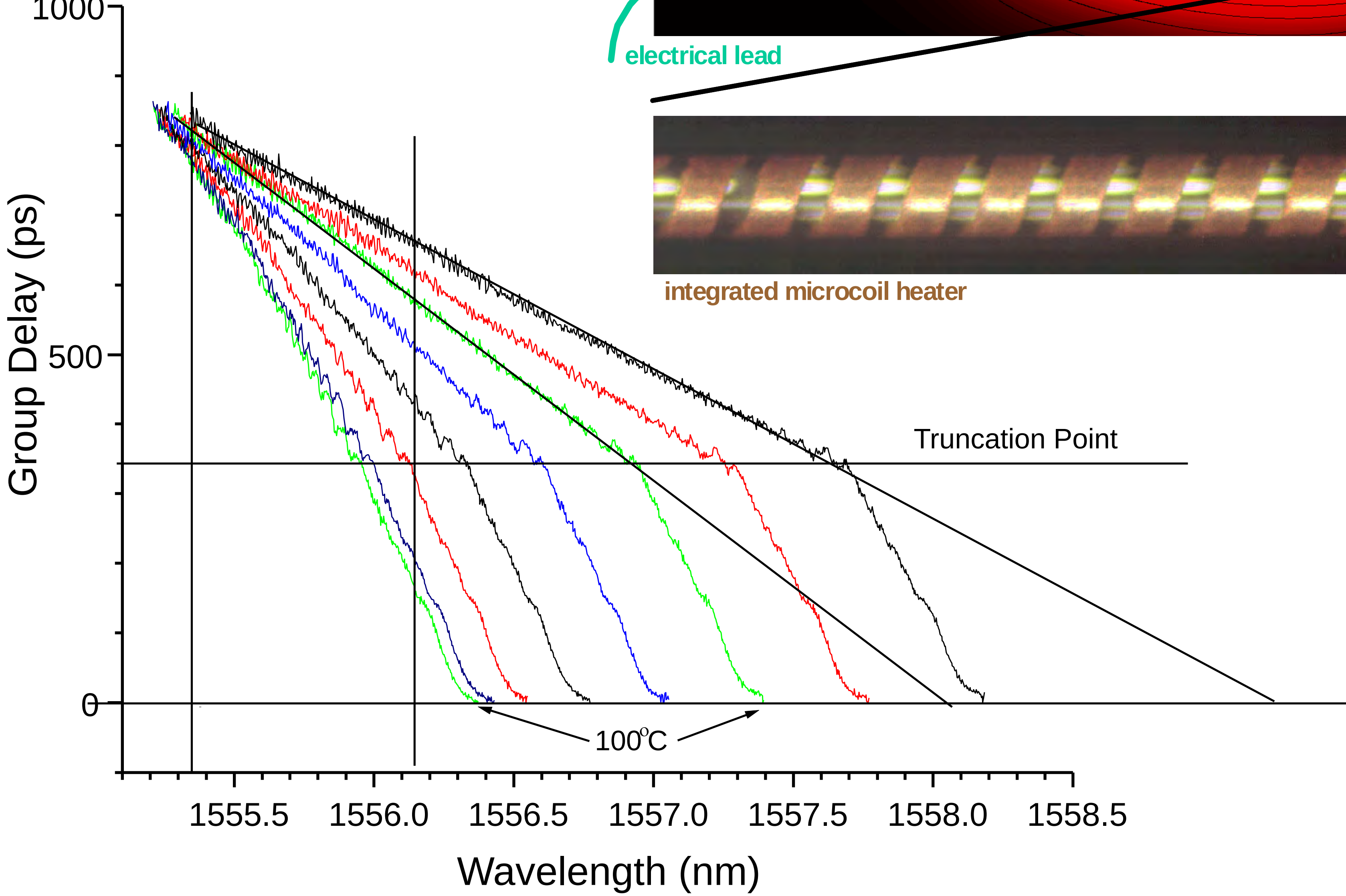


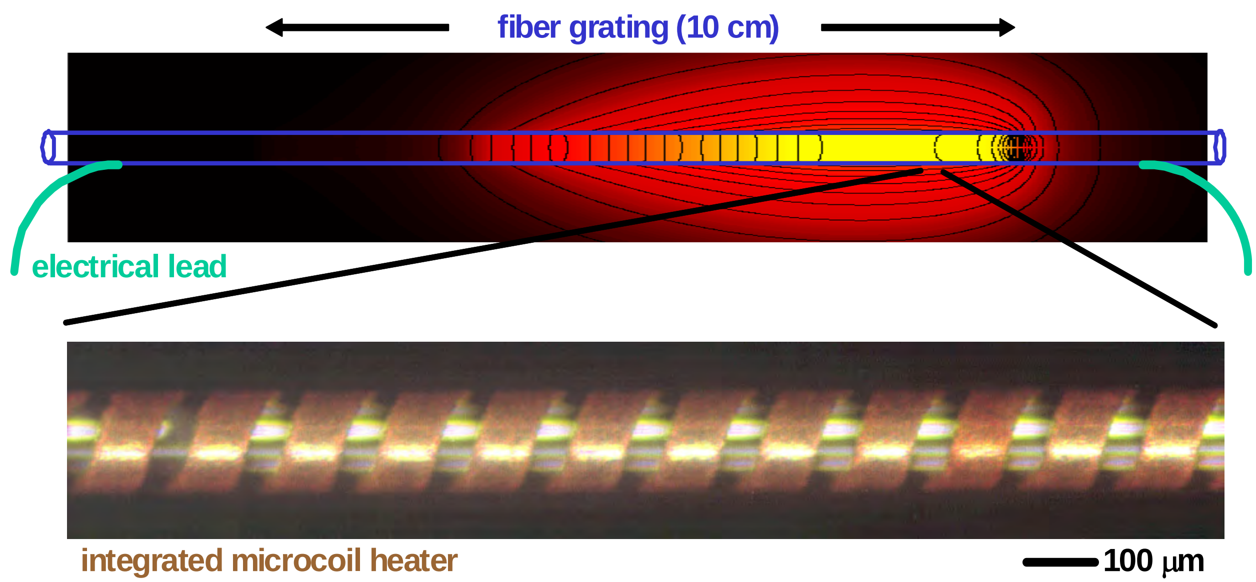
Lucent Technologies
Bell Labs Innovations

Bell Laboratories

Bell Labs -- Optical Fiber Devices

1999

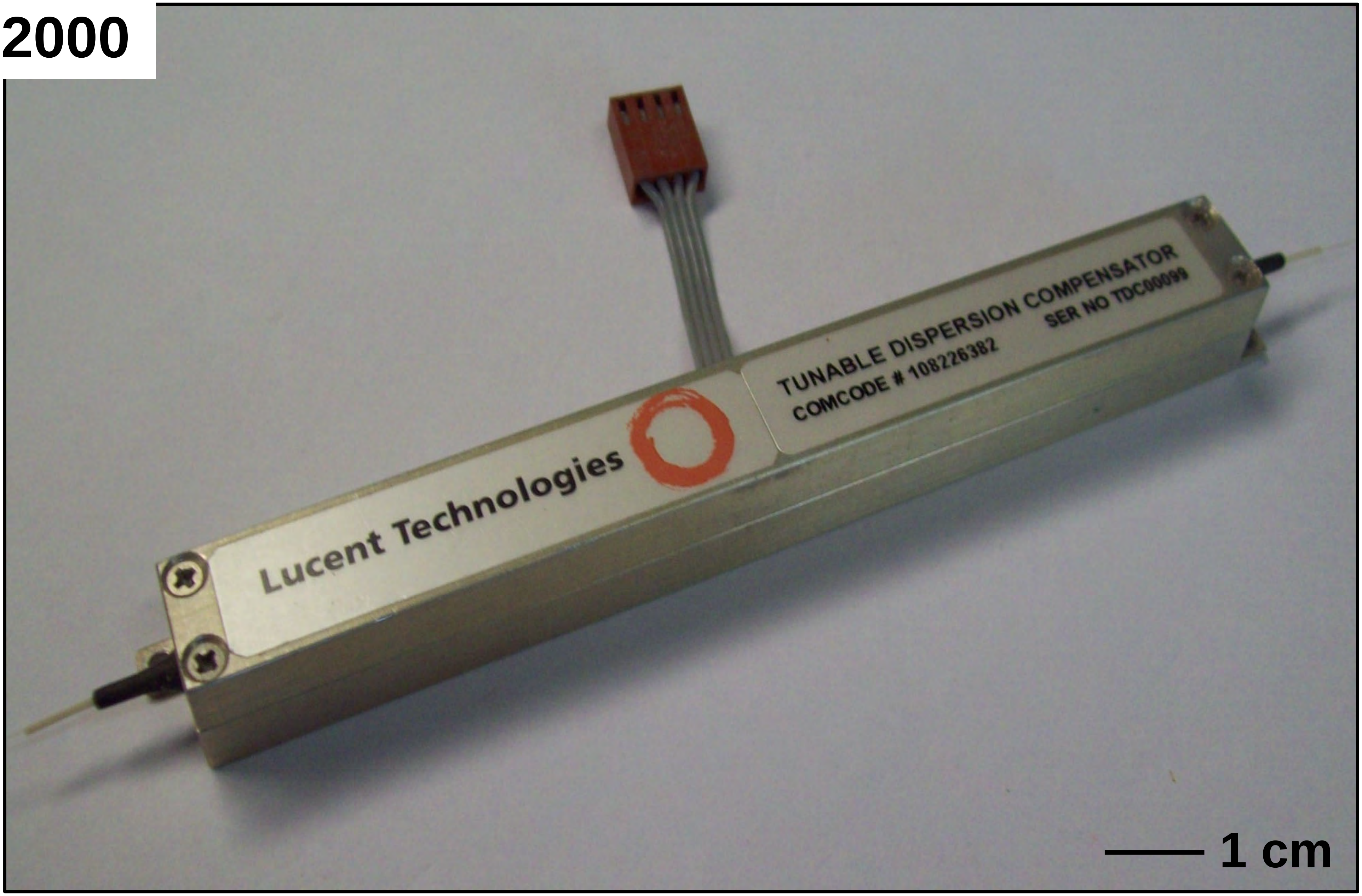




Lucent Technologies
Bell Labs Innovations

Tunable Dispersion Compensator

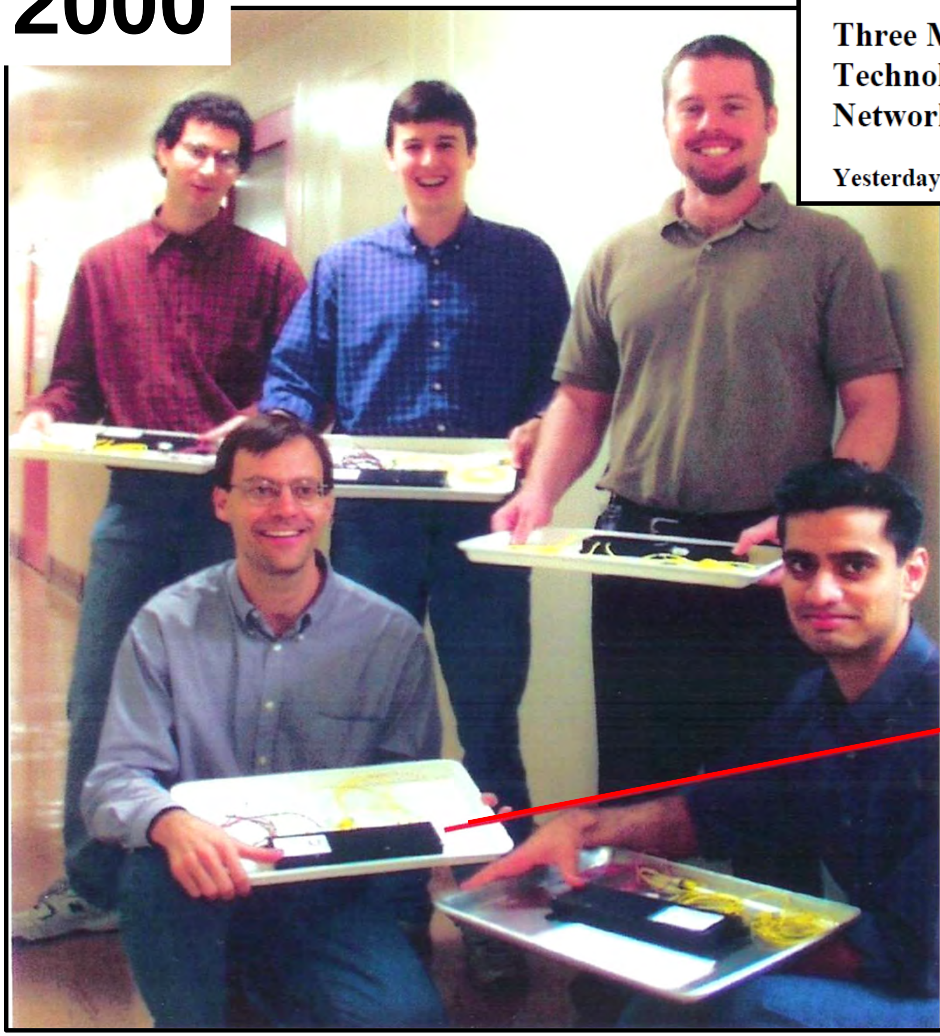
2000



Lucent Technologies
Bell Labs Innovations

Bell Labs Team; Prototypes, Product Launch

2000



Tuesday March 19, 8:07 am Eastern Time

Press Release

SOURCE: Lucent Technologies

Three Magical Ideas From Bell Labs Power Lucent Technologies' New LambdaXtreme(TM) Transport Optical Networking System

Yesterday's Lab Experiments are the Basis of Today's Most Advanced Optical Communications System

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Lucent Technologies
Bell Labs Innovations

Tunable Dispersion Compensation Grating

SPECIALTY FIBER DEVICES

Description and Application

Our Tunable Dispersion Compensator (TDC) is an all-fiber device based on Bell Labs patented fiber Bragg grating technology. It provides a broad dispersion tuning range, and provides a critical solution for dispersion compensation in 40 Gbps systems. Our TDC devices offer dynamically tunable chromatic dispersion over a continuous range. Dispersion can be tuned around zero, or can be offset to meet a range of customer requirements.

For more information, please contact the Specialty Fiber Devices group at:

Phone: 1 800 364 6404
Fax: 1 732 748 7696
email: specialtyfiber@lucent.com

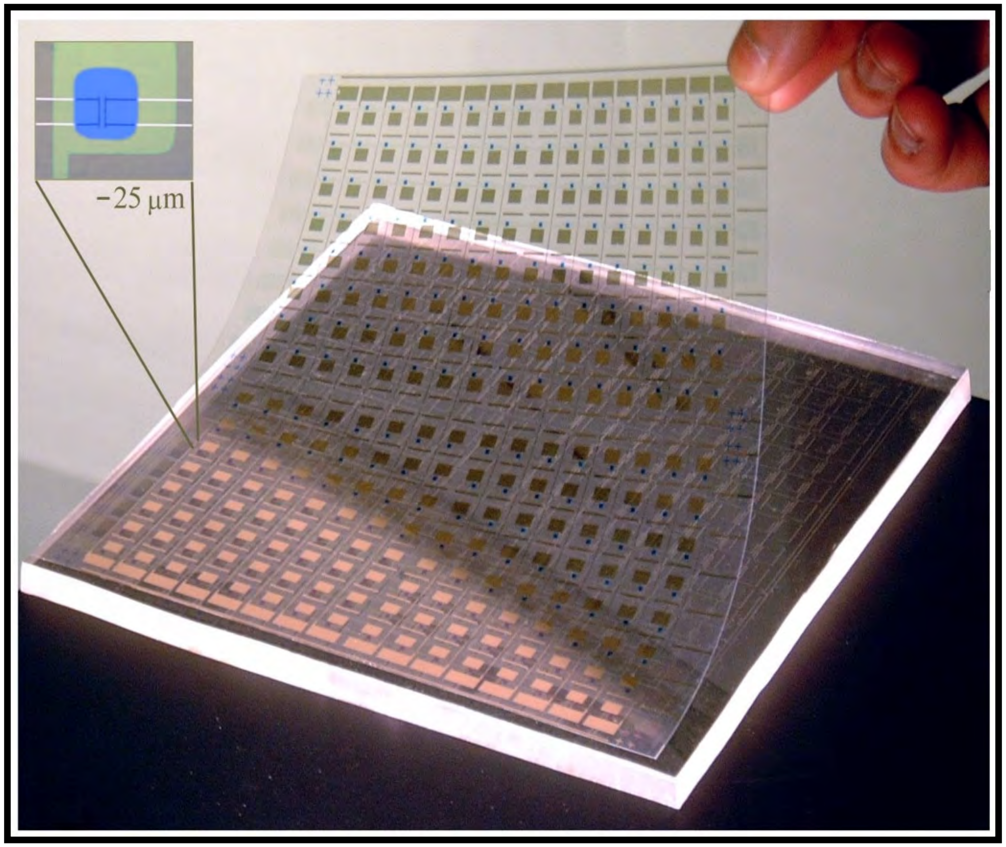
PS-27 March 2001

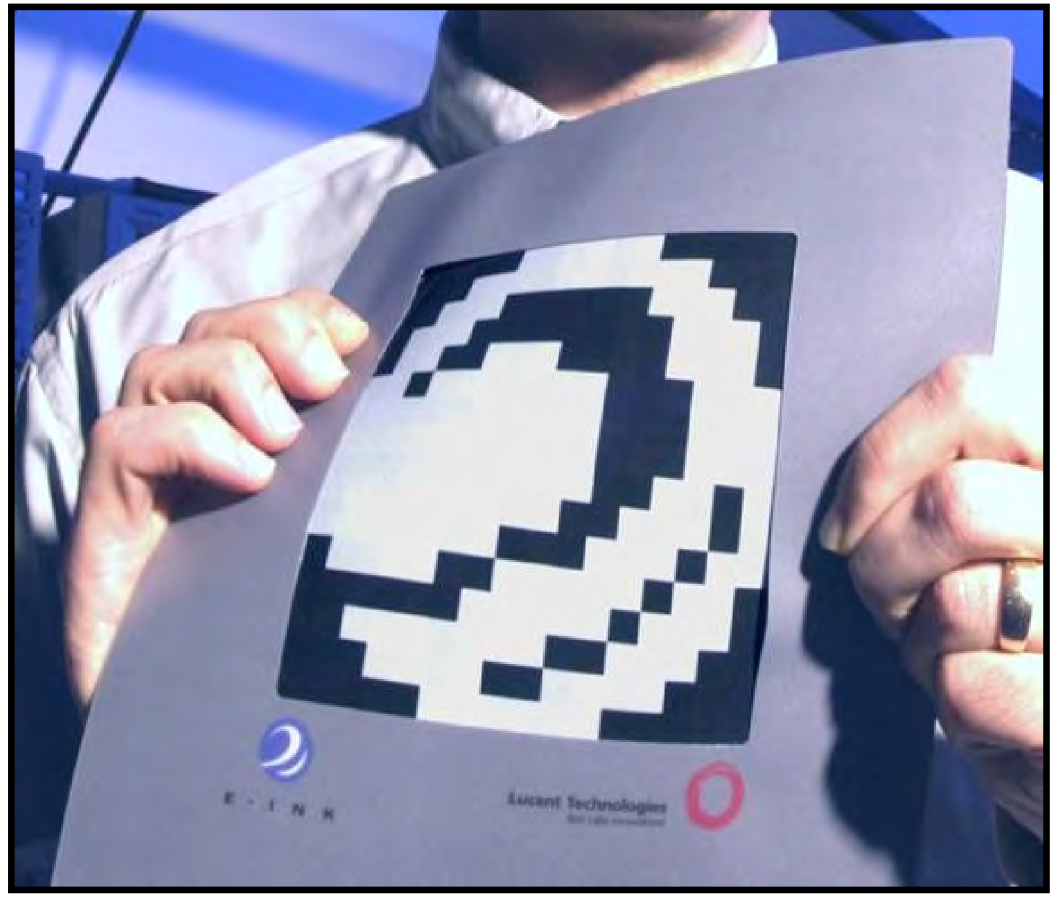
Bell Labs/Lucent Technologies – TDC Fiber Device

- ‘Circuits on fiber’; patent appl: 1997
- Appl identified: 1998-1999
- Prototypes; transfer to OFS: 2000-2001
- ~20 β-units shipped: 2001
- Commercial sales; volume manufact: 2001

4+ years

Soft Lithography, Flexible Electronics and Electronic Paperlike Displays

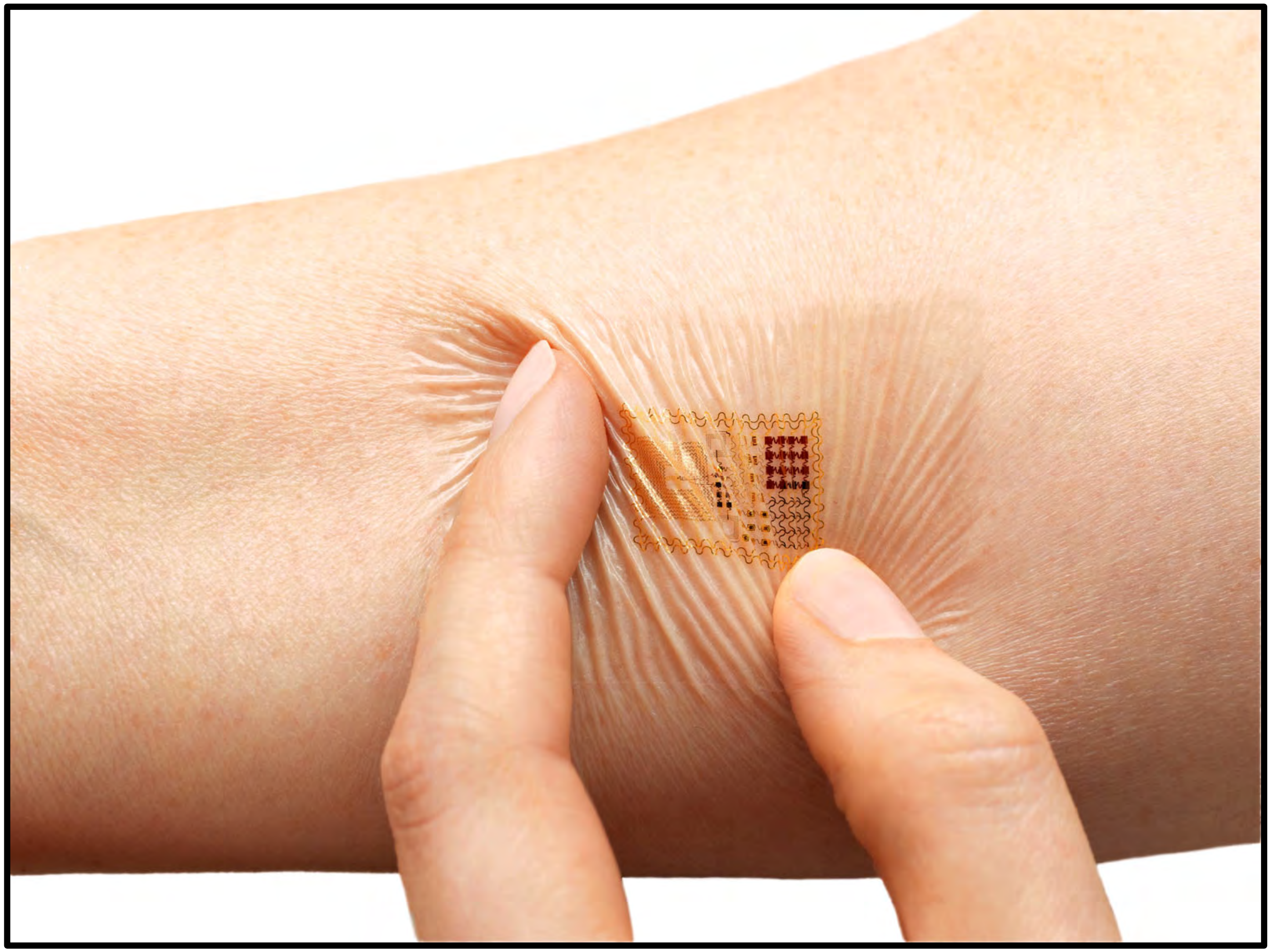




2001

‘Epidermal’ Electronics on Skin, and Free-Standing

Skin Mounted, Deformed



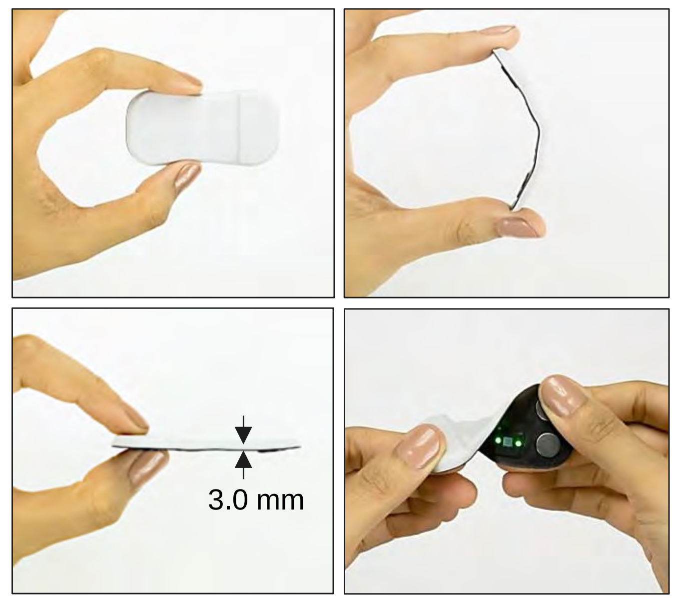
Free Standing

3 mm

2011

First Commercialized ~2011; FDA-Approved in ~2013

1st Stretchable Electronics Product



Acquired by Medidata in 2021

Northwestern

CONTACT US

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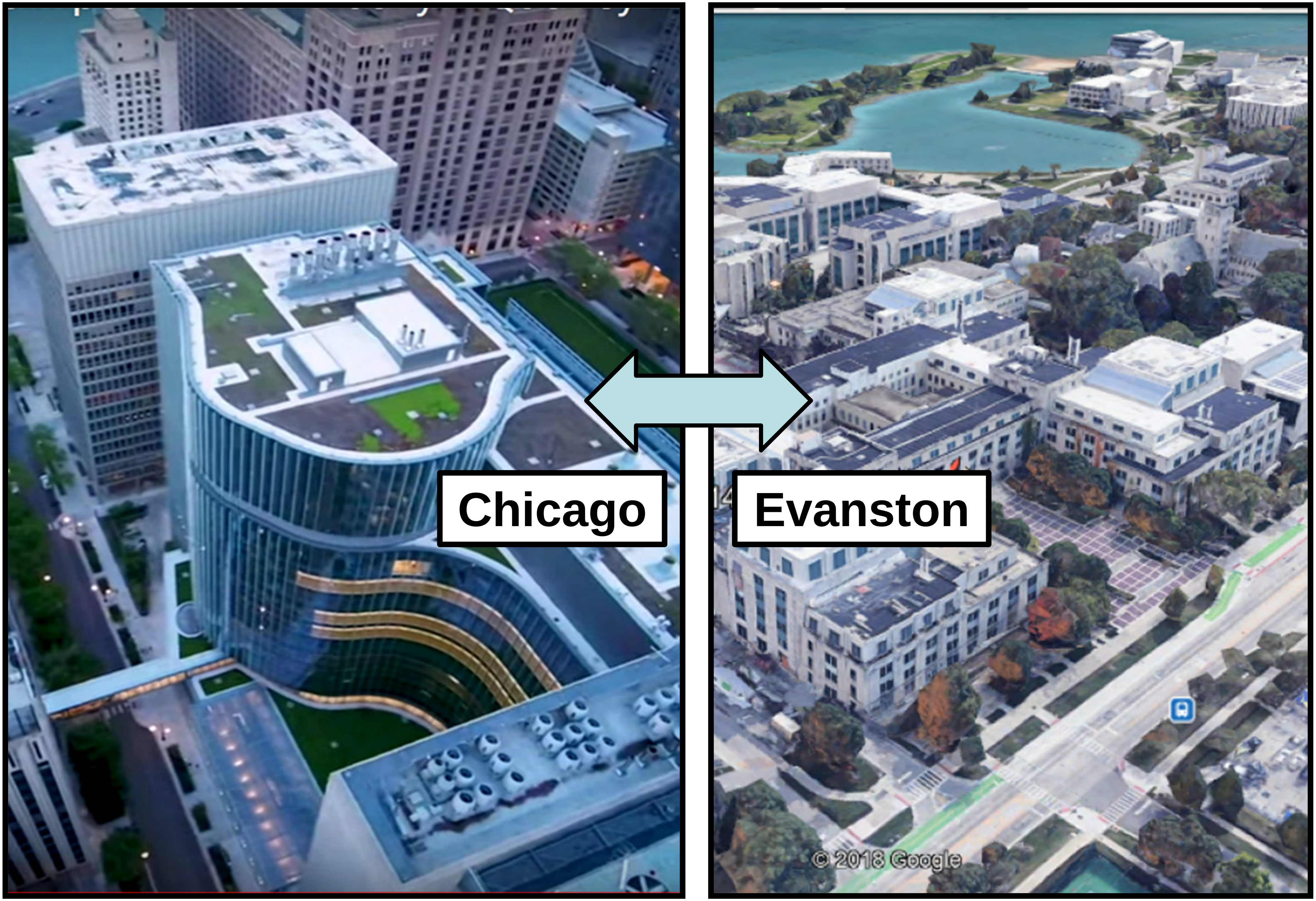
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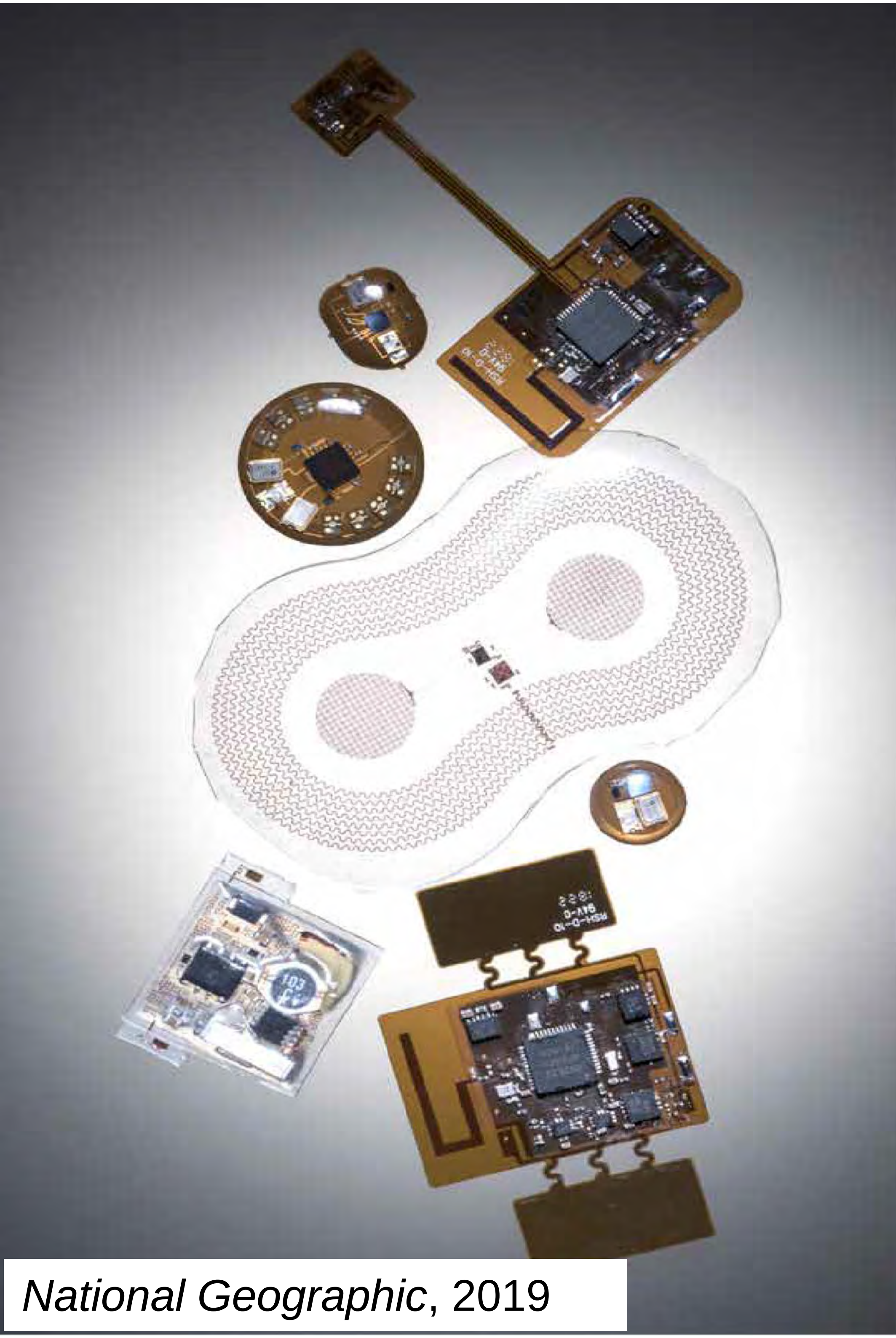

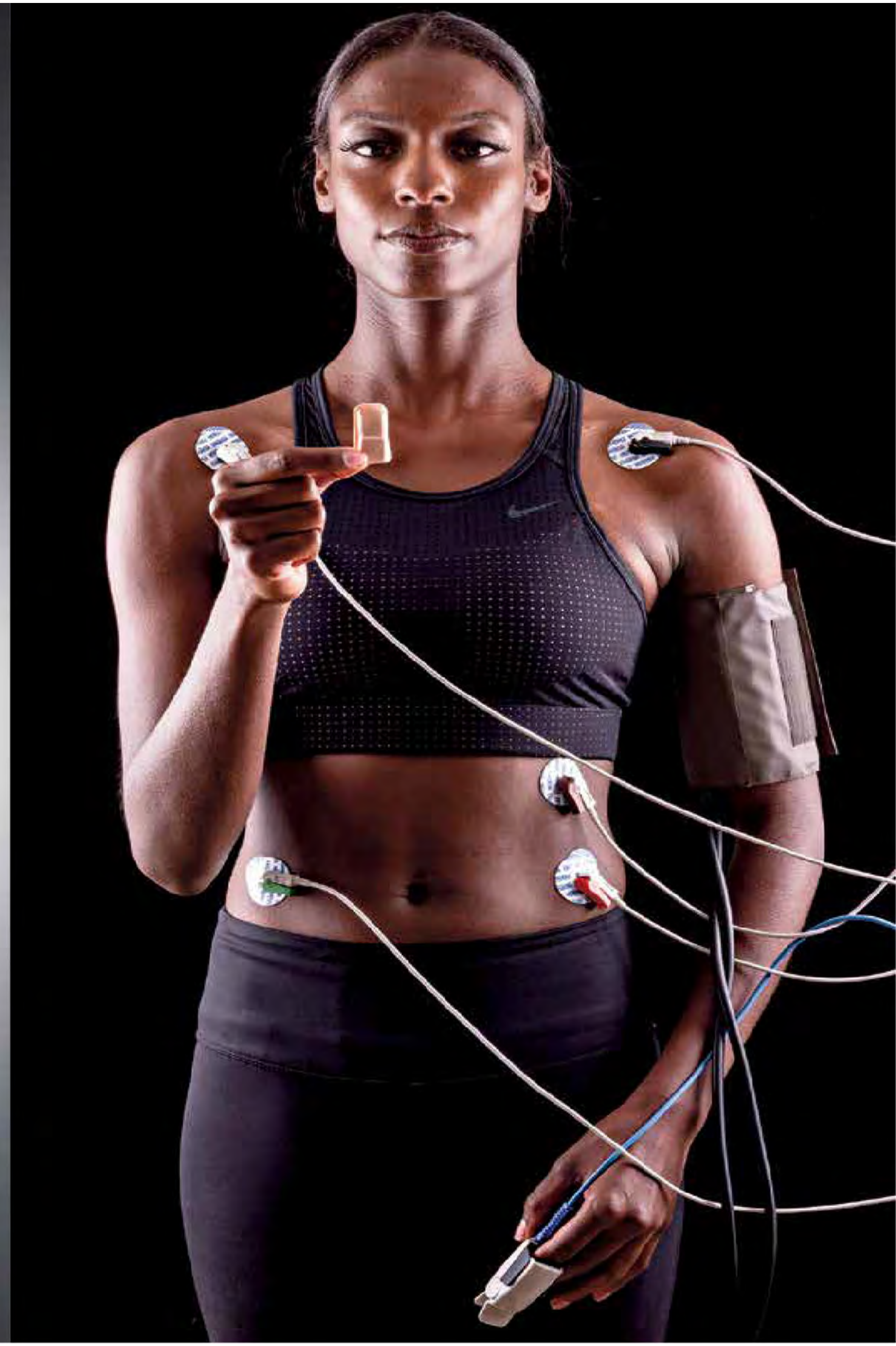

National Geographic, 2019

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Neonatal Intensive Care

Current **_Future_**

QUERREY SIMPSON INSTITUTE FOR BIOELECTRONICS

Northwestern

26 week delivery

IRB approved studies
Lurie Children's Hospital
~200 babies; on-going

Science **363**, 6430, eaau0780 (2019).

QUERREY SIMPSON INSTITUTE FOR BIOELECTRONICS

Interdisciplinary Research

Engineering & Medicine

45 co-authors

Materials Science
Mechanical Engineering
Electrical Engineering
Biomedical Engineering
Computer Science
Dermatology
Neonatology
Pediatrics

Graduate students
Undergraduates
Postdocs
Nurses
Doctors
Faculty

RESEARCH ARTICLE SUMMARY

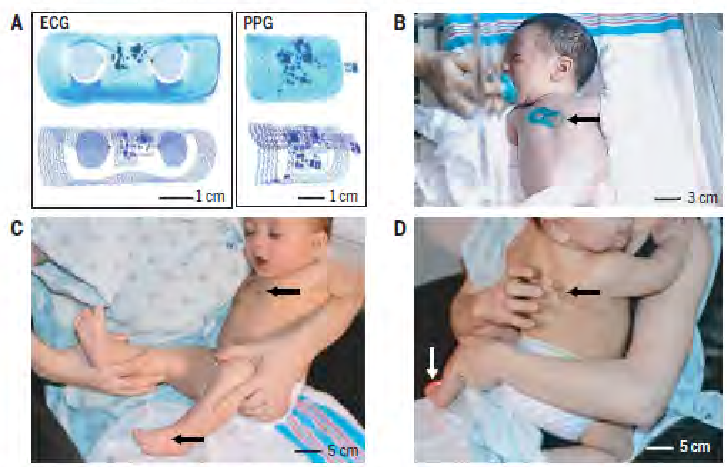
BIOMEDICINE

Binodal, wireless epidermal electronic systems with in-sensor analytics for neonatal intensive care

Ha Uk Chung*, Bong Hoon Kim*, Jong Yoon Lee*, Jungyup Lee*, Zhaoqian Xie*, Erin M. Ibler, KunHyuck Lee, Anthony Banks, Ji Yoon Jeong, Jongwon Kim, Christopher Ogle, Dominic Grande, Yongjoon Yu, Hokyung Jang, Pourya Assem, Dennis Ryu, Jean Won Kwak, Myeong Namkoong, Jun Bin Park, Yechan Lee, Do Hoon Kim, Arin Ryu, Jaeseok Jeong, Kevin You, Bowen Ji, Zhuangjian Liu, Qingze Huo, Xue Feng, Yujun Deng, Yeshou Xu, Kyung-In Jang, Jeonghyun Kim, Yihui Zhang, Roozbeh Ghaffari, Casey M. Rand, Molly Schau, Aaron Hamvas, Debra E. Weese-Mayer, Yonggang Huang, Seung Min Lee, Chi Hwan Lee, Naresh R. Shanbhag, Amy S. Paller†, Shuai Xu†, John A. Rogers†

INTRODUCTION: In neonatal intensive care units (NICUs), continuous monitoring of vital signs is essential, particularly in cases of severe prematurity. Current monitoring platforms require multiple hard-wired, rigid interfaces to a neonate's fragile, underdeveloped skin and, in some cases, invasive lines inserted into their delicate arteries. These platforms and their wired interfaces pose risks for iatrogenic skin injury, create physical barriers for skin-to-skin parental/neonate bonding, and frustrate even basic clinical tasks. Technologies that bypass these limitations and provide additional, advanced physiological monitoring capabilities would directly address an unmet clinical need for a highly vulnerable population.

RATIONALE: It is now possible to fabricate wireless, battery-free vital signs monitoring systems based on ultrathin, "skin-like" measurement modules. These devices can gently and noninvasively interface onto the skin of neonates with gestational ages down to the edge of viability. Four essential advances in engineering science serve as the foundations for this technology: (i) schemes for wireless power transfer, low-noise sensing, and high-speed data communications via a single radio-frequency link with negligible absorption in biological tissues; (ii) efficient algorithms for real-time data analytics, signal processing, and dynamic baseline modulation implemented on the sensor platforms themselves; (iii) strategies for time-synchronized streaming of wireless data from two separate devices; and (iv) designs that enable visual inspection of the skin interface while also allowing magnetic resonance imaging and x-ray imaging of the neonate. The resulting systems can be much smaller in size, lighter in weight, and less traumatic to the skin than any existing alternative.



Wireless, skin-like systems for vital signs monitoring in neonatal intensive care. (**A**) Images and finite-element modeling results for ECG and PPG devices bent around glass cylinders. (**B**) A neonate with an ECG device on the chest. (**C** and **D**) A mother holding her infant with a PPG device on the foot and an ECG device on the chest (C) and on the back (D).

RESULTS: We report the realization of this class of NICU monitoring technology, embodied as a pair of devices that, when used in a time-synchronized fashion, can reconstruct full vital signs information with clinical-grade precision. One device mounts on the chest to capture electrocardiograms (ECGs); the other rests on the base of the foot to simultaneously record photoplethysmograms (PPGs). This binodal system captures and continuously transmits ECG, PPG, and (from each device) skin temperature data, yielding measurements of heart rate, heart rate variability, respiration rate, blood oxygenation, and pulse arrival time as a surrogate of systolic blood pressure. Successful tests on neonates with gestational ages ranging from 28 weeks to full term demonstrate the full range of functions in two level III NICUs.

ON OUR WEBSITE

Read the full article at http://dx.doi.org/10.1126/science.aau0780

The thin, lightweight, low-modulus characteristics of these wireless devices allow for interfaces to the skin mediated by forces that are nearly an order of magnitude smaller than those associated with adhesives used for conventional hardware in the NICU. This reduction greatly lowers the potential for iatrogenic injuries.

CONCLUSION: The advances outlined here serve as the basis for a skin-like technology that not only reproduces capabilities currently provided by invasive, wired systems as the standard of care, but also offers multipoint sensing of temperature and continuous tracking of blood pressure, all with substantially safer device-skin interfaces and compatibility with medical imaging. By eliminating wired connections, these platforms also facilitate therapeutic skin-to-skin contact between neonates and parents, which is known to stabilize vital signs, reduce morbidity, and promote parental bonding. Beyond use in advanced hospital settings, these systems also offer cost-effective capabilities with potential relevance to global health. ■

The list of author affiliations is available in the full article online.
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†Corresponding author. Email: apaller@northwestern.edu (A.S.P.); stevexu@northwestern.edu (S.X.); jrogers@northwestern.edu (J.A.R.)

Cite this article as H. U. Chung *et al.*, *Science* 363, eaau0780 (2019). DOI: 10.1126/science.aau0780

Scaled Deployments into India, Pakistan, Zambia, Kenya and Ghana – from 2020 to present

BILL & MELINDA GATES foundation

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Nature Medicine **26**, 418 (2020).

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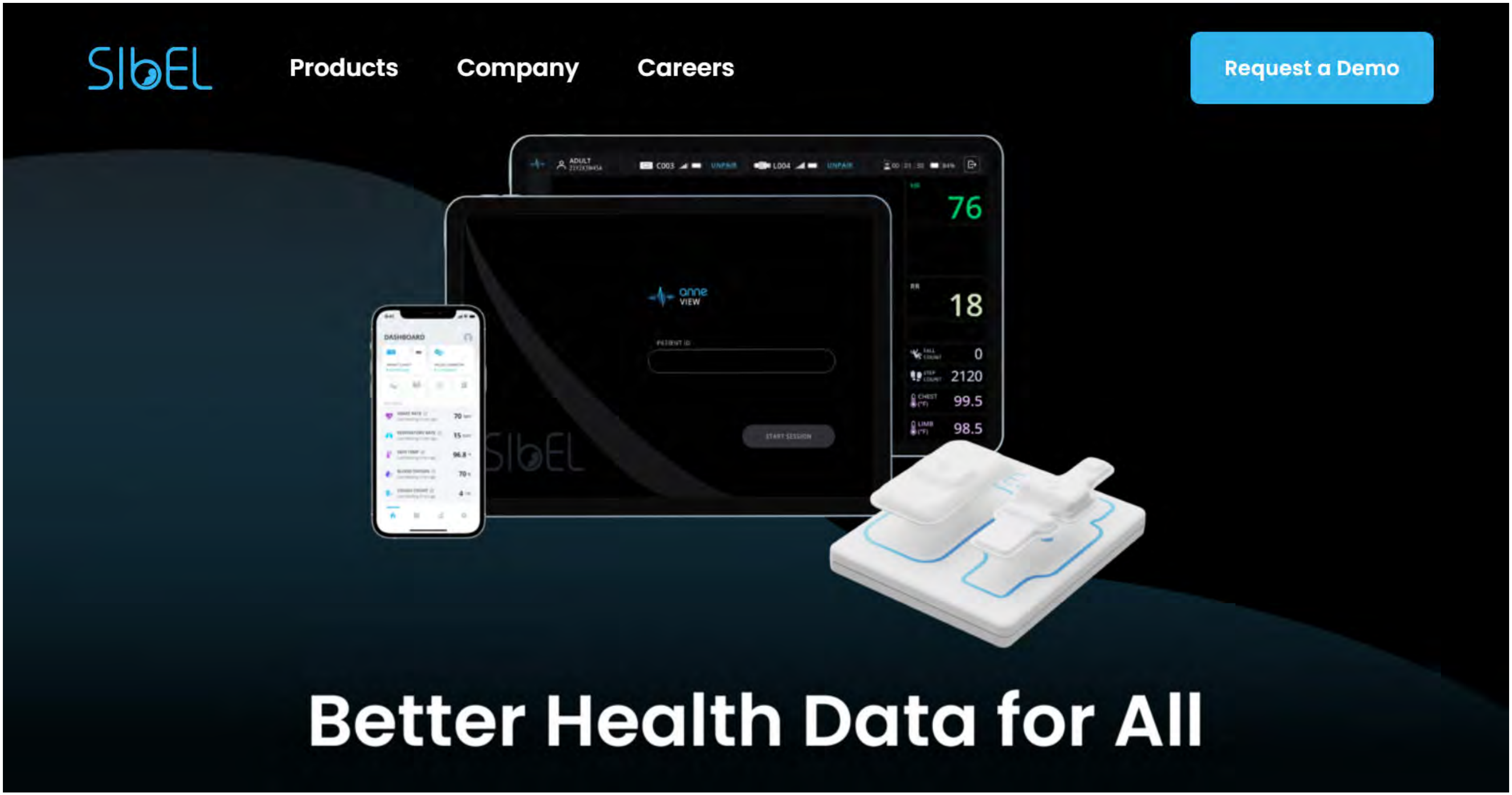


Recent Milestones

1st Wireless NICU

Montreal

No wires, more cuddles: Montreal Children's smart monitoring for babies in its NICU

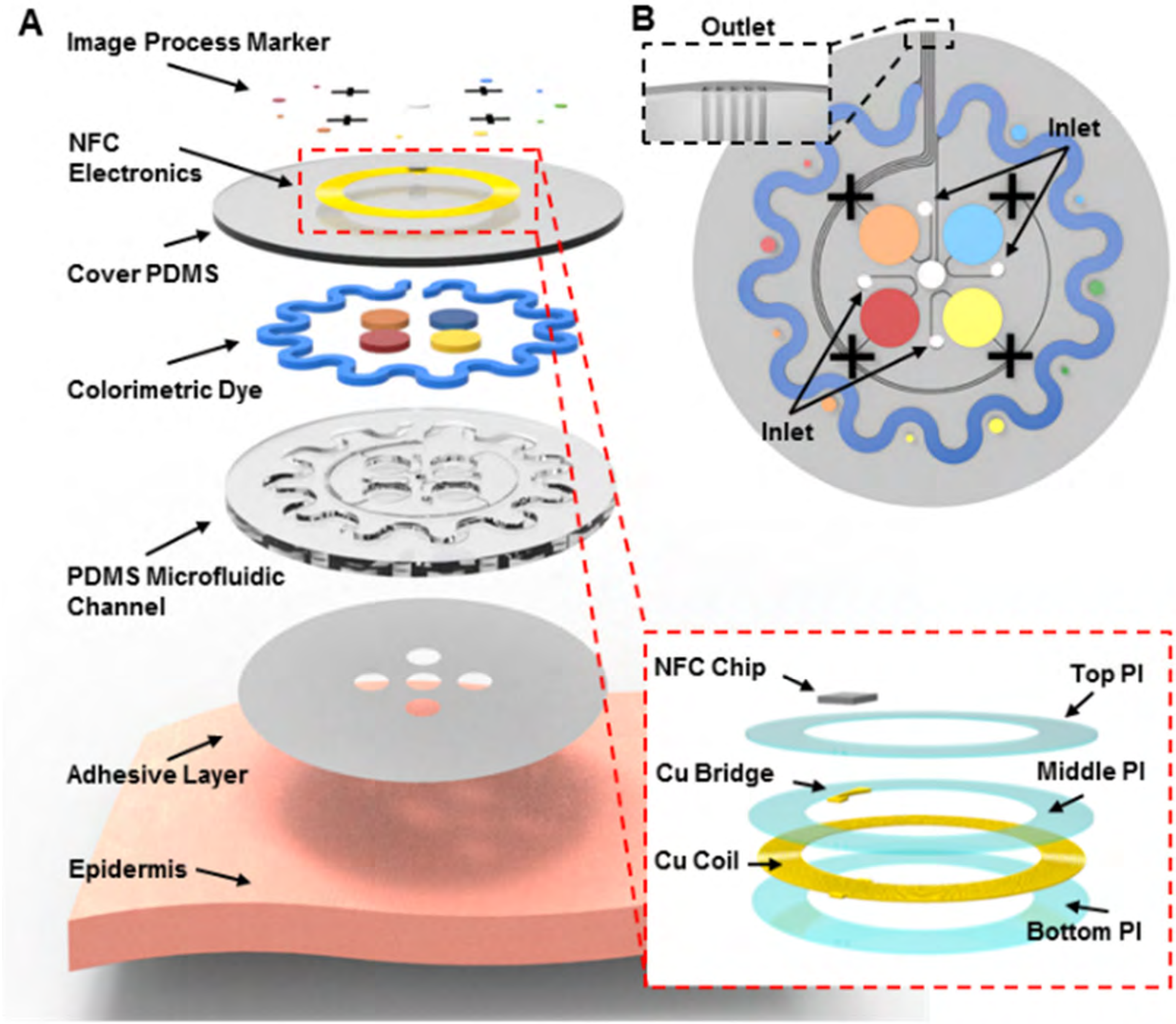
Mothers who have tried the new wireless technology say it has made life easier as it allows for better bonding experiences with their newborn babies. (Source: Picture This Productions/MUHC)

Financing

Partnerships:
Drager, GE, Spacelabs

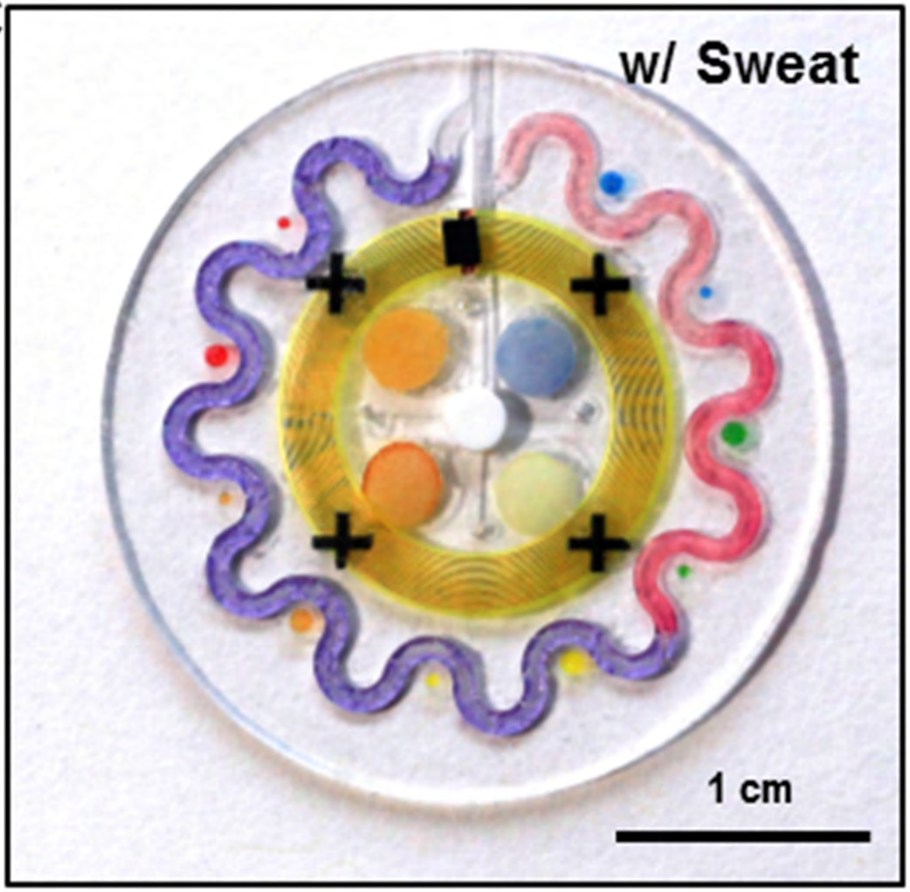
Sibel Health - Team

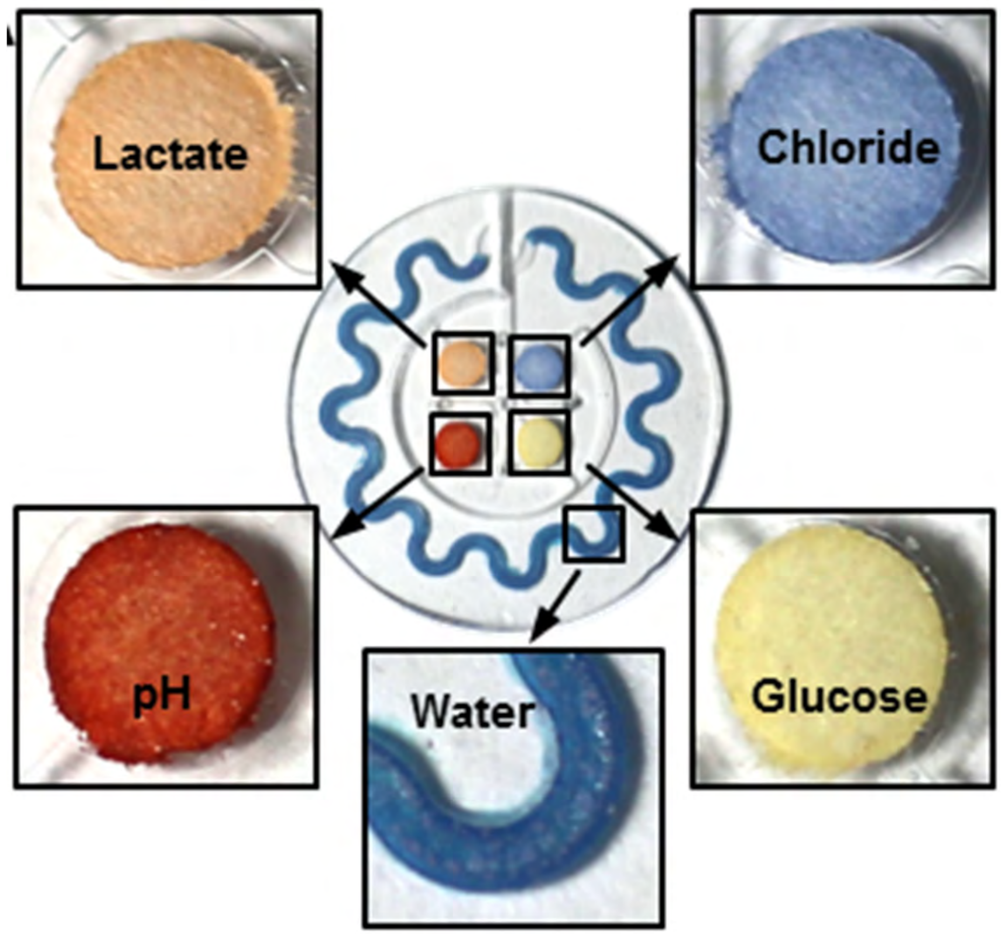
Epidermal Microfluidic Devices and Sweat Analytics



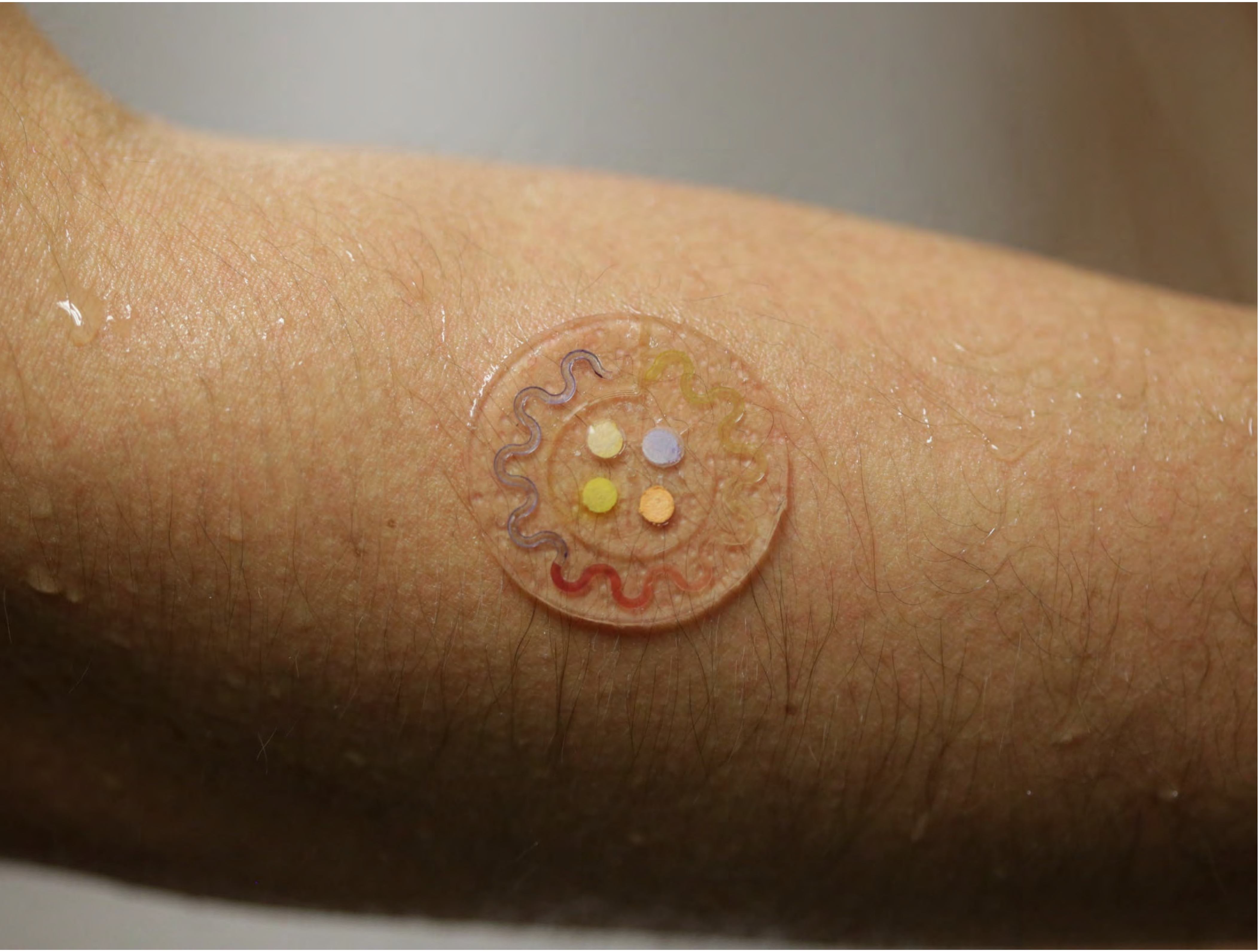
Sci. Transl. Med **8**, 366ra165 (2016).

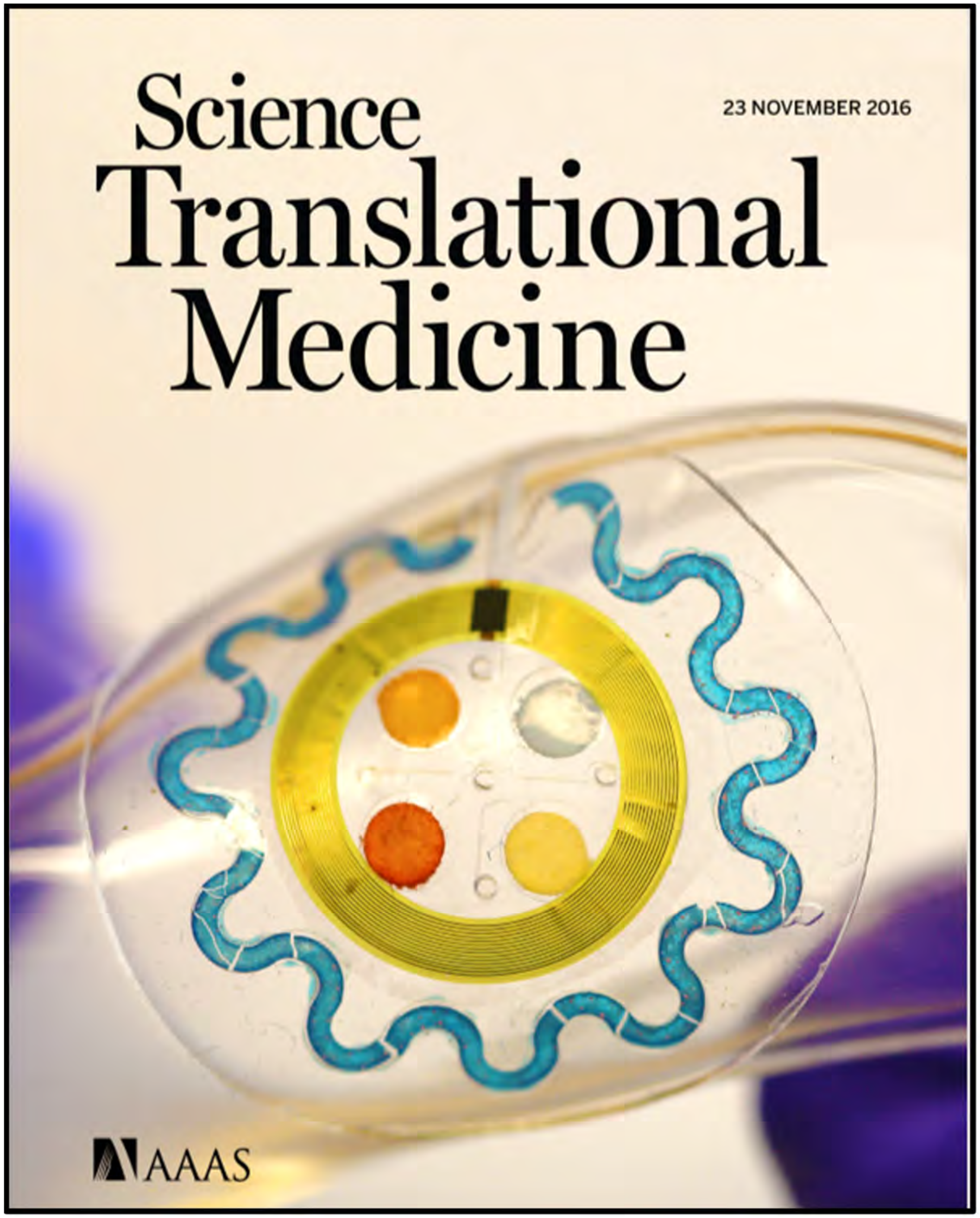
Epidermal Microfluidic Devices and Sweat Analytics





Sci. Transl. Med **8**, 366ra165 (2016).





BIOSENSORS

A soft, wearable microfluidic device for the capture, storage, and colorimetric sensing of sweat

Ahyeon Koh,[1*] Daeshik Kang,[1,2*] Yeguang Xue,[3] Seungmin Lee,[1] Rafal M. Pielak,[4] Jeonghyun Kim,[1,5] Taehwan Hwang,[1] Seunghwan Min,[1] Anthony Banks,[1] Philippe Bastien,[6] Megan C. Manco,[7] Liang Wang,[3,8] Kaitlyn R. Ammann,[9] Kyung-In Jang,[1] Phillip Won,[1] Seungyong Han,[1] Roozbeh Ghaffari,[10] Ungyu Paik,[5] Marvin J. Slepian,[9] Guive Balooch,[4] Yonggang Huang,[3] John A. Rogers[1†]

Capabilities in health monitoring enabled by capture and quantitative chemical analysis of sweat could complement, or potentially obviate the need for, approaches based on sporadic assessment of blood samples. Established sweat monitoring technologies use simple fabric swatches and are limited to basic analysis in controlled laboratory or hospital settings. We present a collection of materials and device designs for soft, flexible, and stretchable microfluidic systems, including embodiments that integrate wireless communication electronics, which can intimately and robustly bond to the surface of the skin without chemical and mechanical irritation. This integration defines access points for a small set of sweat glands such that perspiration spontaneously initiates routing of sweat through a microfluidic network and set of reservoirs. Embedded chemical analyses respond in colorimetric fashion to markers such as chloride and hydronium ions, glucose, and lactate. Wireless interfaces to digital image capture hardware serve as a means for quantitation. Human studies demonstrated the functionality of this microfluidic device during fitness cycling in a controlled environment and during long-distance bicycle racing in arid, outdoor conditions. The results include quantitative values for sweat rate, total sweat loss, pH, and concentration of chloride and lactate.

INTRODUCTION

A convergence of advances in materials, mechanics design, and specialized device architectures is beginning to establish the foundations for a next generation of wearable electronic technologies, where sensors and other functional components reside not in conventional rigid packages mounted on straps or bands but instead interface directly on the skin (*1*, *2*). Specifically, devices that combine soft, low-modulus physical properties and thin layouts allow robust, nonirritating, and long-lived interfaces with the human epidermis (*2*). This developing field involves innovative ideas in both organic and inorganic functional materials, where mechanical and manufacturing science play important roles. Although most devices described in the literature focus on measurement of physical characteristics such as motion, strain, stiffness, temperature, thermal conductivity, biopotential, electrical impedance, and related parameters (*1*, *3*–*10*), complementary information—often with high clinical value—could be realized through capture and biochemical analysis of biofluids such as sweat (*11*, *12*).

As a representative biofluid, sweat is of particular interest owing to its relative ease of noninvasive collection and its rich content of important biomarkers including electrolytes, small molecules, and proteins (*13*, *14*). Despite the importance of sweat analysis in biomedicine, interpreting information from sweat can be difficult due to uncertainties in its relationship with other biofluids, such as interstitial fluid and blood, and due to the lack of biomedical appliances for direct sampling and detection of multiple biomarkers without evaporation (*15*). In situ quantitative analysis of sweat is nevertheless of great interest for monitoring of physiologic health status (for example, hydration state) and for the diagnosis of disease (for example, cystic fibrosis) (*16*, *17*). Existing systems for whole-body sweat collection have been confined to the laboratory (*18*), where standard chemical analysis technologies (chromatography, mass spectroscopy, and electrochemical detection) can reveal the composition of collected samples (*19*). Recent attempts to detect and collect sweat simultaneously involve direct contact with sensors on the skin (for example, temporary tattoo) where fabric or paper substrates accumulate sweat for electrochemical and/or optical assessment (*20*). For instance, electrochemical sensors directly laminated on the epidermis can detect chemical components, such as sodium ions and lactate, in real time (*21*–*23*). Colorimetric responses in functionalized porous substrates can yield chemical information, such as the pH of sweat, and further enable simple quantitative assays using devices capable of capturing high-quality digital images, such as smartphones (*24*–*26*). Radio frequency identification systems, which can be integrated on top of porous materials for wireless information transfer, provide additional functionality (*27*, *28*). These and related technologies can quantify sweat generation rate (*27*), but because the sweat gland density and overall areas are typically unknown, the total sweat rate and volumetric loss cannot be determined accurately. In addition, the most widely explored formats do not simultaneously reveal the concentration of multiple chemical components, nor do they offer full compatibility with the growing availability of soft, skin-mounted electronics, physical sensors, radio technologies, and energy storage devices.

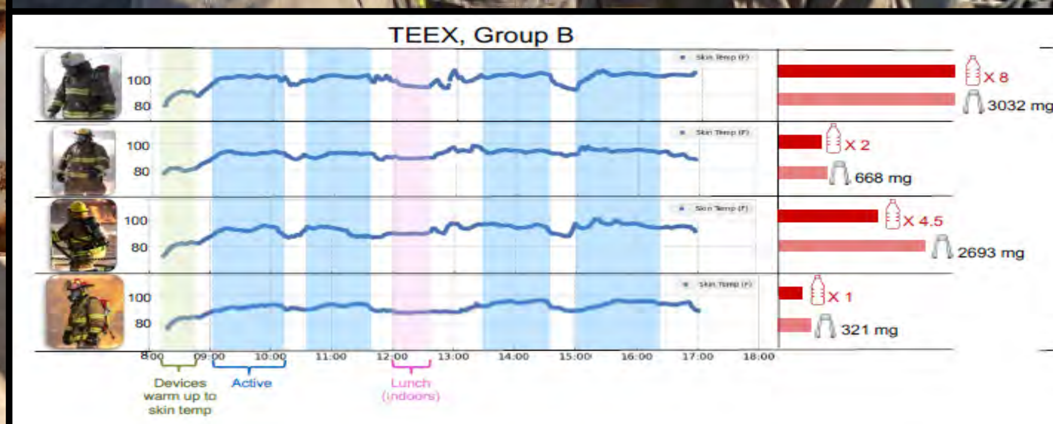
[1]Department of Materials Science and Engineering, Frederick Seitz Materials Research Laboratory, University of Illinois at Urbana-Champaign, Urbana, IL 61801, USA. [2]Department of Mechanical Engineering, Ajou University, Suwon 443-749, Korea. [3]Departments of Civil and Environmental Engineering, Mechanical Engineering, and Materials Science and Engineering, Northwestern University, Evanston, IL 60208, USA. [4]L'Oréal Technology Incubator, San Francisco, CA 94107, USA. [5]Department of Energy Engineering, Hanyang University, Seoul 133-791, Korea. [6]L'Oréal Research and Innovation, Aulnay-sous-Bois, France. [7]L'Oréal Early Clinical, Clark, NJ 07066, USA. [8]Department of Chemical and Biological Engineering, Institute of Chemical Machinery and Process Equipment, Zhejiang University, Hangzhou 310027, People's Republic of China. [9]Department of Medicine and Biomedical Engineering, Sarver Heart Center, University of Arizona, Tucson, AZ 85724, USA. [10]MC10 Inc., Cambridge, MA 02140, USA.
*These authors contributed equally to this work.
†Corresponding author. Email: jrogers@illinois.edu


Gx
EPICORE
BIOSYSTEMS

Commercial Spot – Lionel Messi, 2023

Hydration for Worker Safety – the 'Industrial Athlete'

w/ Chevron and Fluor



Epicore Biosystems - Team

From Scientific Discovery to Engineering Development and Commercial Deployment

Three Short Stories: *From the Lab to the Real World*

1) **MIT – Semiconductor Metrology**

2) **Bell Laboratories – Lightwave Communications**

3) **Northwestern University – Medical Technology**

Some Observations

- Long, difficult, sustained efforts required – >5 years

- Staff up only after derisking the tech, w/ clear visibility on products, revenues; run lean, fast, efficient

- Build strong teams, core competencies, aligned interests; be wary of paid consultants, outside advisors

- Keep things simple, straightforward – tech, structures, teams, plans, business models

Some More Observations

- Gap between research and product is enormous
- Competitive landscape changes rapidly, unpredictably
- Respond quickly to changing market conditions, user feedback, new opportunities
- Need platform technology with specific, market pull
- Sustained engagement w/ the originating academic research group is powerful

Some More Observations

- Build from the bottom-up, on product excellence;
  not from the top-down on pitch decks, investors

- Focus on products and impact, not exit strategies

- Partner with large, established entities;
  leverage product-oriented, non-dilutive funding

- Think at the full, system level –
  hardware, software, algos, user interf

My Background, Experiences

1989-1995: <u>PhD student at MIT (Prof. K. Nelson)</u>
Picosecond laser technology
MIT 10k Business Plan Competition

1995-1997: <u>Junior Fellow at Harvard (Prof. G. Whitesides)</u>
Soft lithography, soft microsystems tech.
Active Impulse Systems (start, sold)

1997-2002: <u>MTS, Department Head at Bell Laboratories</u>
Flexible electronics, fiber optics, microfluidics
E-Ink Display Backplanes (IP licensed)
Fiber Devices (TDC product launch)

2002-2016: <u>Professor, University of Illinois at Urbana/Champaign</u>
Diverse materials, tech.; bio-integrated systems
Semprius (start -> X-Celeprint, Xdisplay, Sense Ph)
MC10 (start, sold); Neurolux (start), Wearifi (start)

2016-present: <u>Professor, Northwestern University</u>
Diverse materials, tech.; bio-integrated systems
Institute for Bioelectronics (launch)
Epicore Biosys (start); Sibel (start); Rhaeos (start)