SCALING OF CARBON NANOBUD FILM PRODUCTION FOR COMMERCIAL APPS IN TOUCH AND DISPLAY DEVICES

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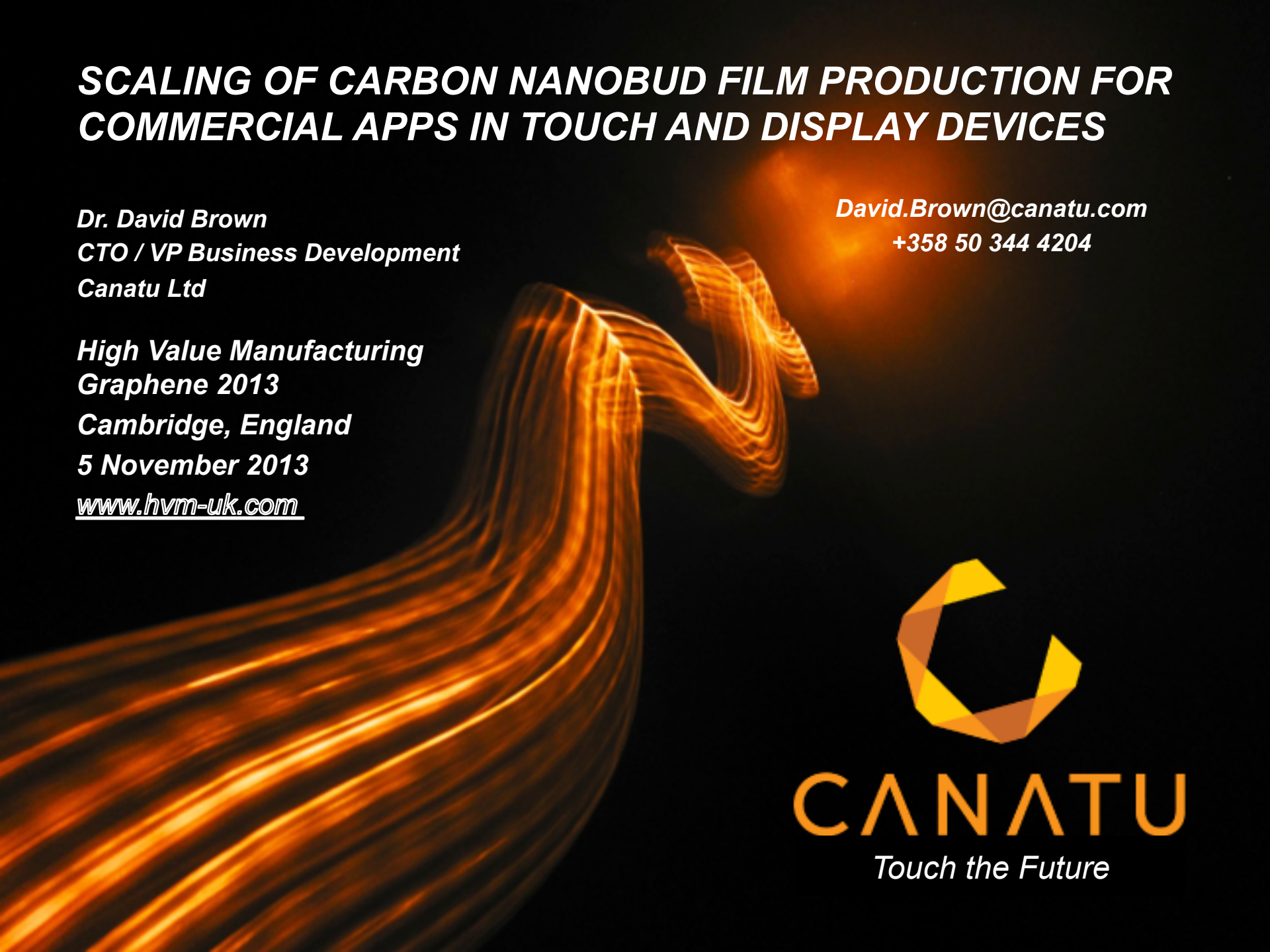
High Value Manufacturing
Graphene 2013
Cambridge, England
5 November 2013
www.hvm-uk.com



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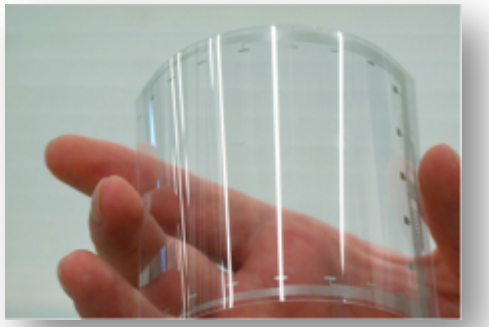
Canatu in Brief

Business started 2008

- Technology spin-out from Aalto University in 2004
- Over 20M$ in investment to date
- Over 150 patents & applications in 18 families
  - Material, manufacturing, devices, designs



Transitioning from Development to Production

- 20 employees and 1200 m^2 of production space
- Numerous ongoing Joint Development Projects
- Medium scale production facility ready now

Commercial Production to start in 2013

- 1st touch design wins targeted Q4 2013
- In 1st touch products targeted Q1 2014

White Bull 2010 & 12 Bully Award · TECHTOUR 30 · TiE 50 2011 FINALIST · TECHNOPOLIS iNNOVATE! 2010 · RED HERRING WINNER 100 EUROPE · RED HERRING WINNER 100 GLOBAL · Global Cleantech 100 Summit and Gala

Canatu is leading the next phase in electronics development

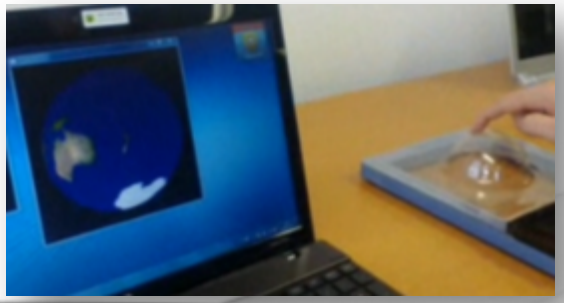
New functions & form factors drive market

Consumers want

- Large “use” size but small “carry” size
- Robust / Unbreakable
- Fashion / Style
- High performance
- Low price
- Ubiquitous implementation

Producers want

- Clear differentiation
- Low cost
- Clean and safe
- High volume
- New uses



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Flexible/Formable Product Evolution

LGE

SMK / Canatu

Canatu

Unbreakable

Rigid curved

Rigid 3D

Foldable

Flexible

Rollable

E-ink

Nokia

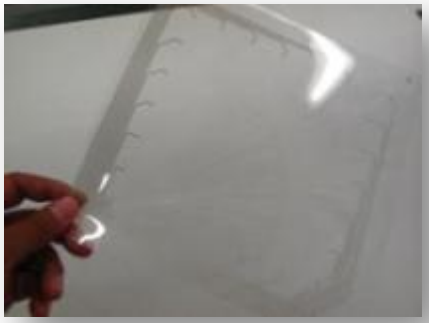
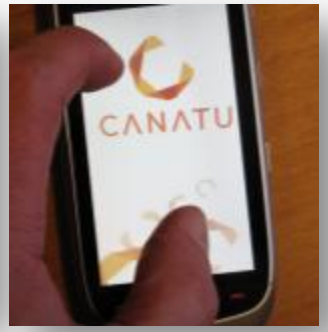
E-roll

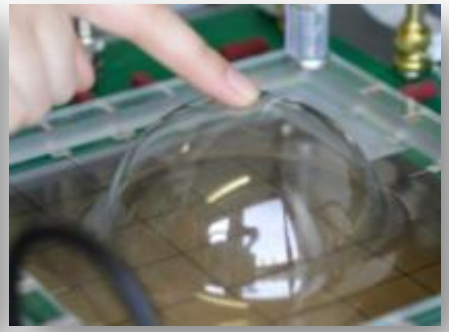
Samsung

Canatu Addresses Roadblocks in Stages

Core Competence

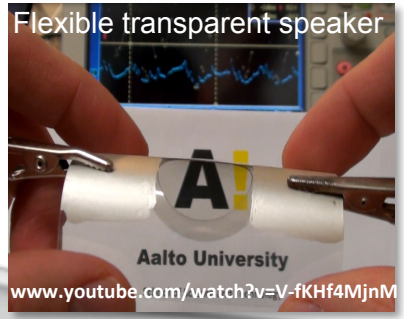
- Novel carbon nanomaterials, synthesis processes and R2R manufacturing
- Robust, flexible, formable, bendable thin film electronic components

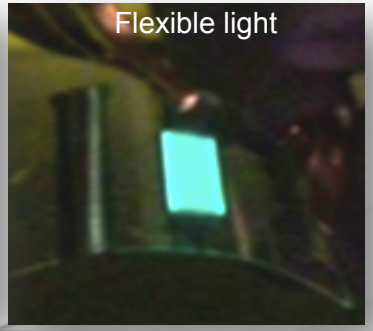



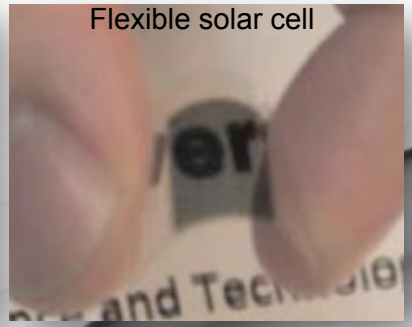



Business Model

- Produce and Sell: Robust, flexible, formable, bendable touch sensors (now)
  Solar cells, supercaps, speakers, ICs, lights, displays (later)







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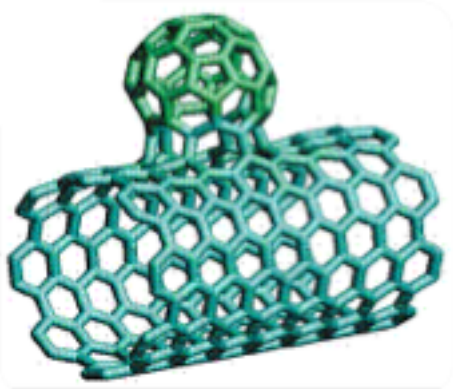
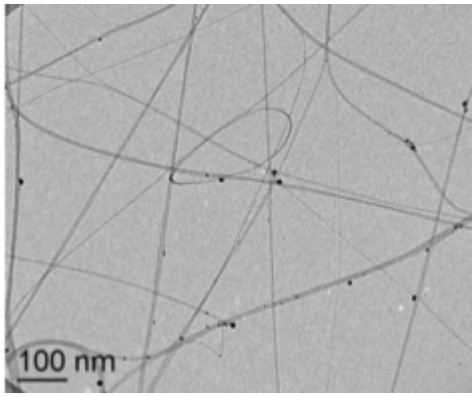
Carbon NanoBud® (CNB)

Hybridization of Carbon Nanotubes (CNTs) and Fullerenes (C_{60})

- **Conductive or Semiconductive**
- **Chemically Functionalizable**
- **Flexible & Stretchable**
- **Transparent and non-reflective**
- **Robust**



NanoBud® Molecule



NanoBud® Network

NanoBud® Film

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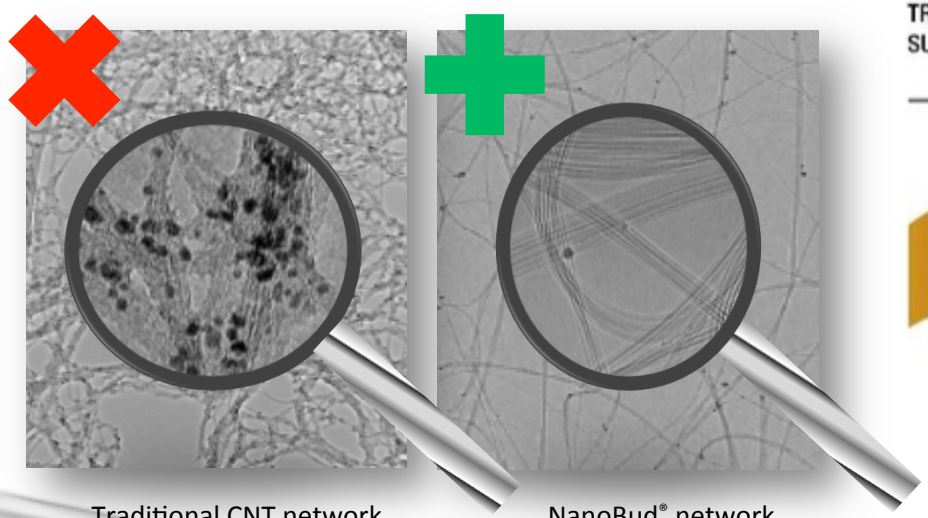
Canatu invented the new Direct Dry Printing® (DDP) manufacturing process

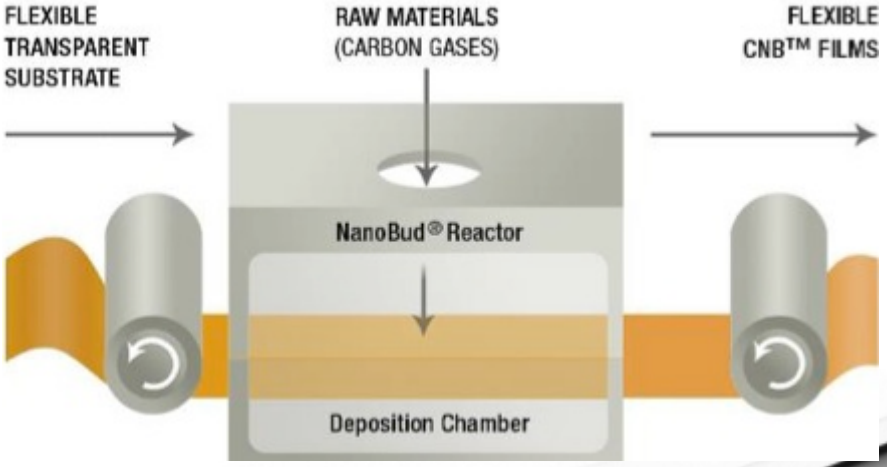
Combination of high purity material synthesis and aerosol printing

- **Low Materials and Capital Costs** (Carbon based / atmospheric pressure)
- **High Quality** (pure, dispersed, ready to use)
- **High Volume** (R2R film production)
- **Easily Customizable** (in-situ & laser patterning)
- **Green** (no wet / toxic chemistry)



Traditional CNT network
(before purification)

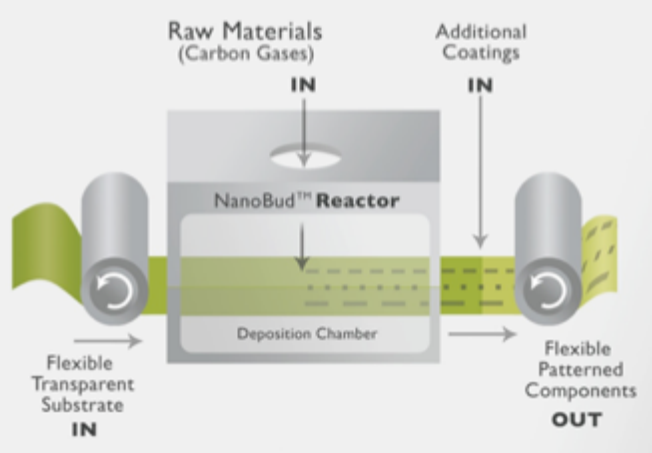
NanoBud® network
(no need for purification)



Roll-to-Roll **Direct Dry Printing®**
(in-situ patterning)

Rapid Dry Deposition and Patterning

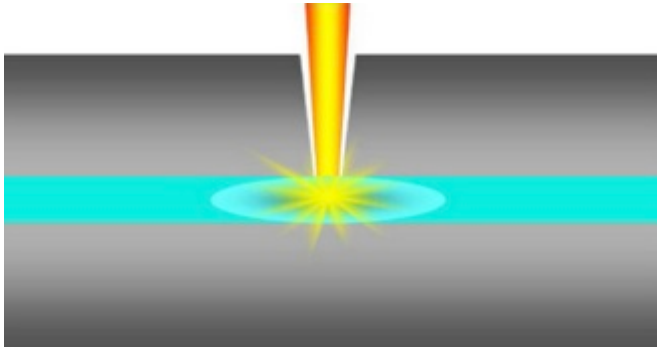
Coarse patterning: Direct Dry Printing®

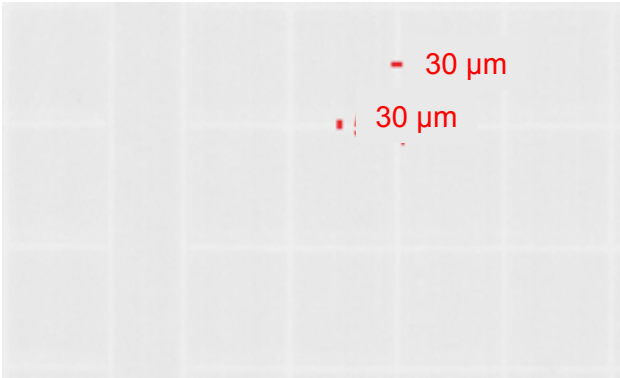


Process benefits:

- Simple
- High Volume
- High Purity
- Agile Production

Fine patterning: Laser ablation





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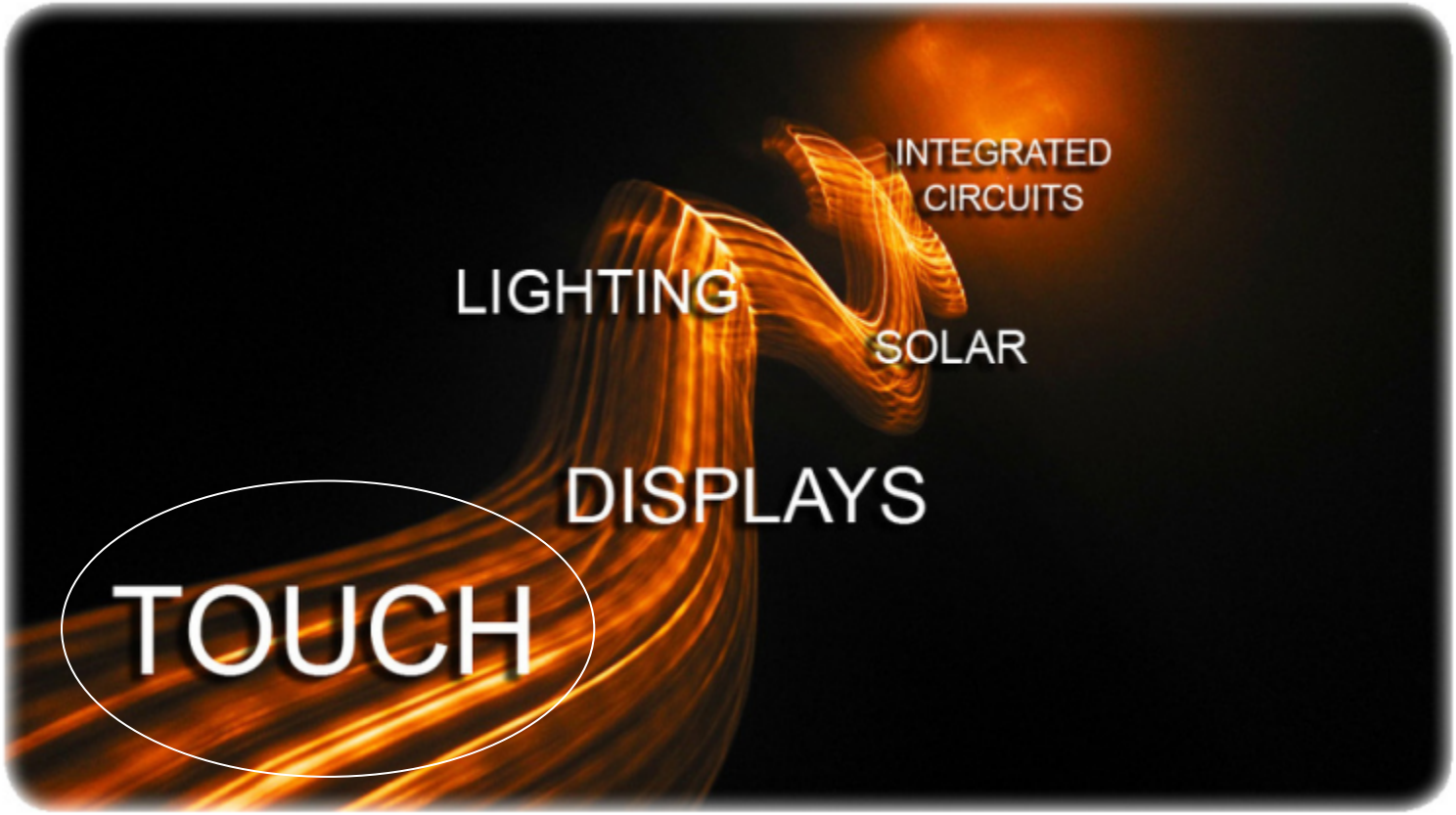
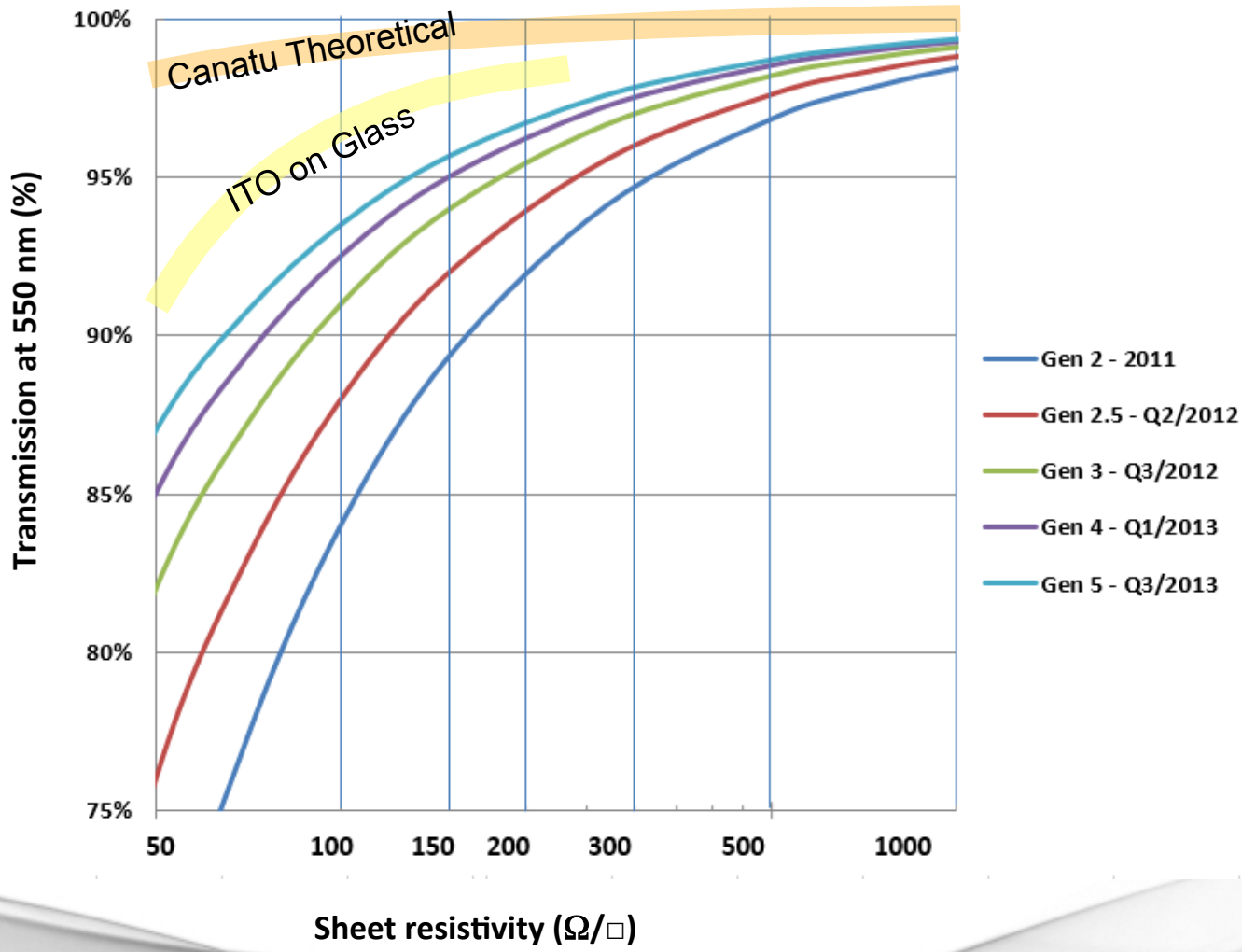
Canatu's Product Roadmap



- Canatu's conductive films are transparent, flexible & formable
- Enable new device structures, shapes & functions

Continuous Development of CNB™ Film

Gen 5 Released in October 2013



Examples:

100 Ω/□ at 94%
150 Ω/□ at 96%
270 Ω/□ at 98%

This is substrate-normalized transmission:
T = 100% - CNB Absorbance

Continuous Development of CNB™ Film

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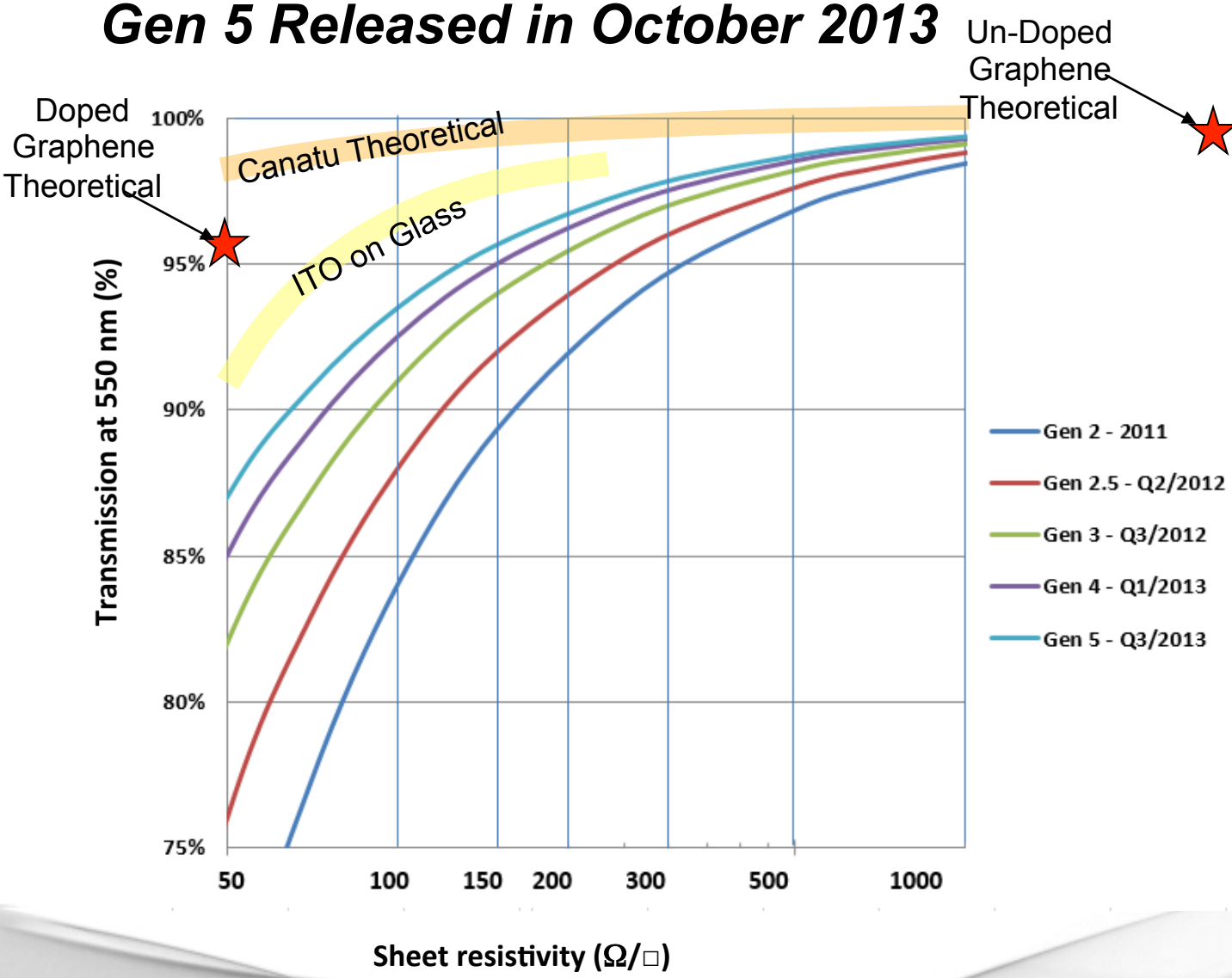

Examples:

100 Ω/□ at 94%
150 Ω/□ at 96%
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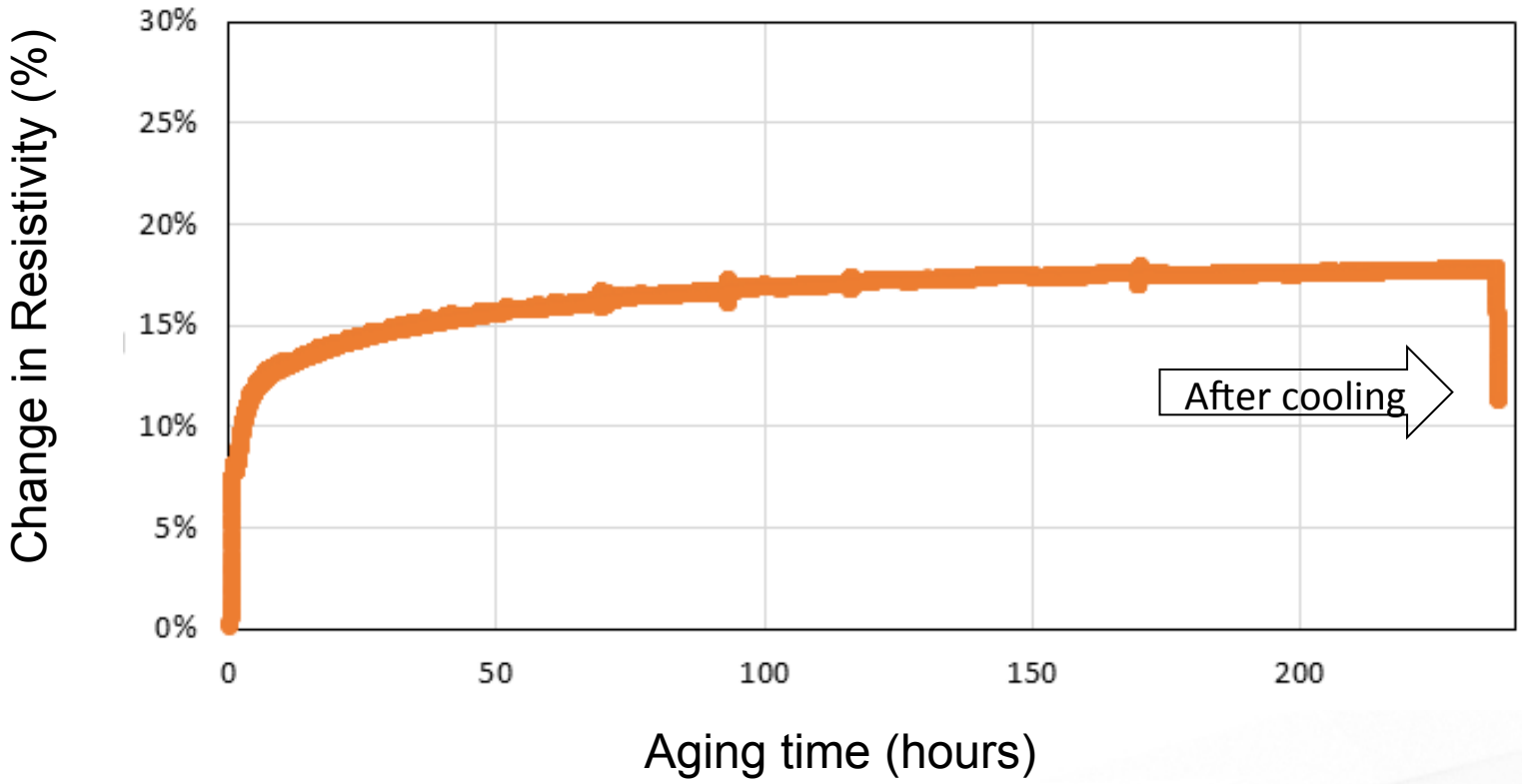
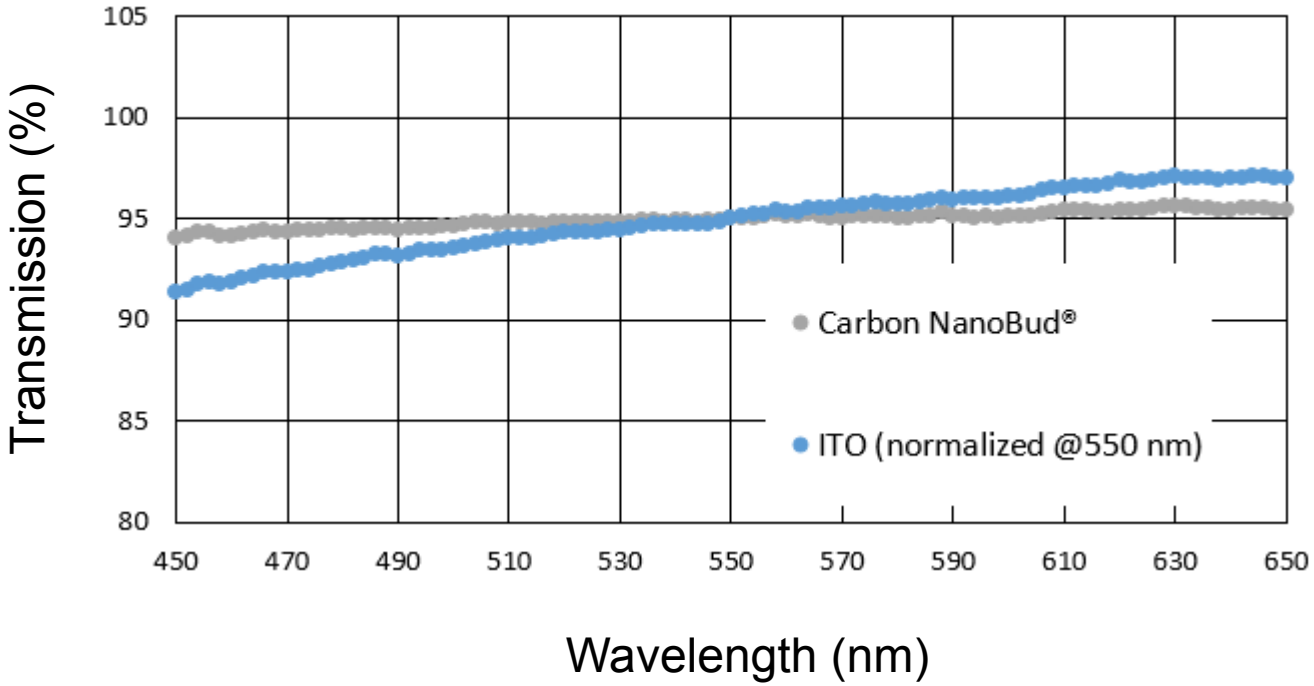
This is substrate-normalized transmission:
T = 100% - CNB Absorbance

CNB™ Films are Stable

Damp heat test: 60˚C / 90% RH, naked CNB film



CNB™ Films are color neutral



CNB™ color space:

L* = 98
a* = 0 ± 0.1
0 < b* < 1

Note: CNB and ITO transmissions are substrate normalized.

CNB™ Films Have Almost no Haze

Haze only 0.15%

- Haze in Carbon NanoBud® material is negligible, within measurement accuracy

Consequently:

- Haze in CNB™ touch sensors dictated by choice of substrate and OCA
- Same low haze over the whole CNB™ sheet resistivity range

Results in crisp, high contrast images in touch displays

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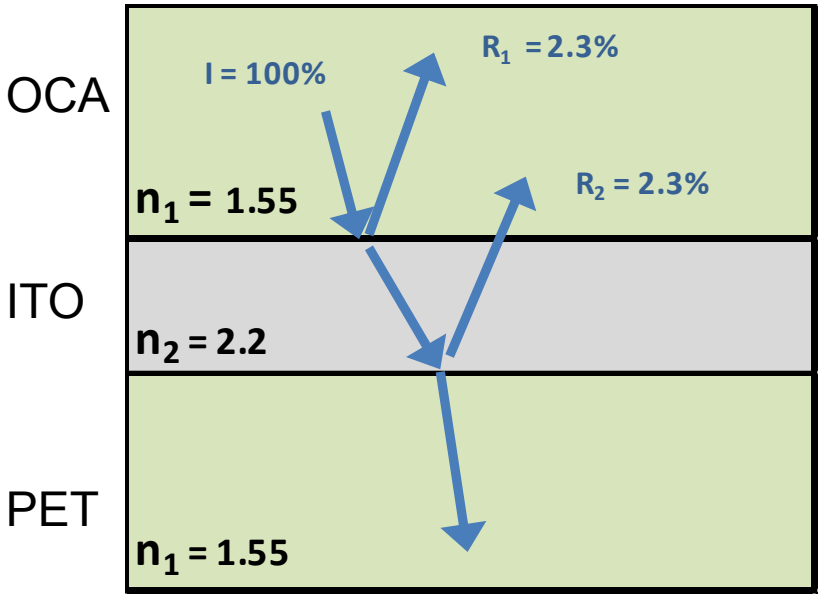
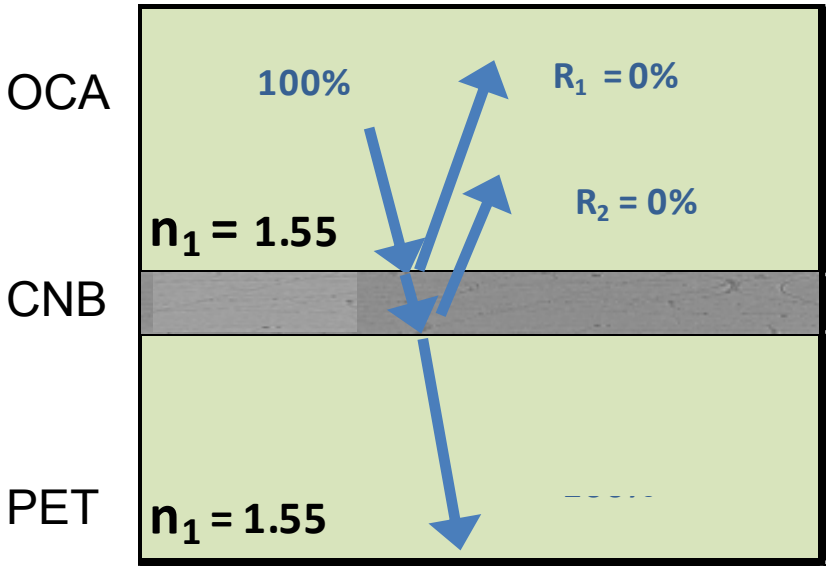
CNB™ Films Have Almost no Reflections

ITO Stack



CNB Stack



$$R = \left|\frac{n_1 - n_2}{n_1 + n_2}\right|^2$$

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Real life display readability

Display washed out under ambient light

Effect worsened by reflecting touch screens

Example: off-the-shelf mobile device with LCD display & touch

Dark room

0 lux

Bright office

1000 lux

Indoor sunlight

40 000 lux

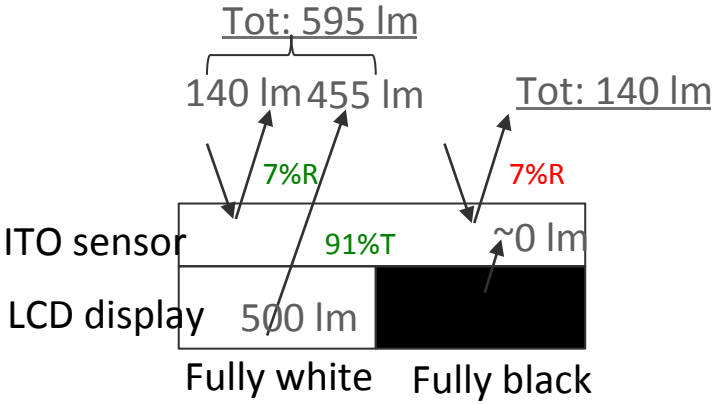
Courtesy: Displaymate Technologies *http://www.displaymate.com/Tablet_Brightness_ShootOut_1.htm*

Solution: Carbon Nanobud® Sensors Enhance Display Contrast

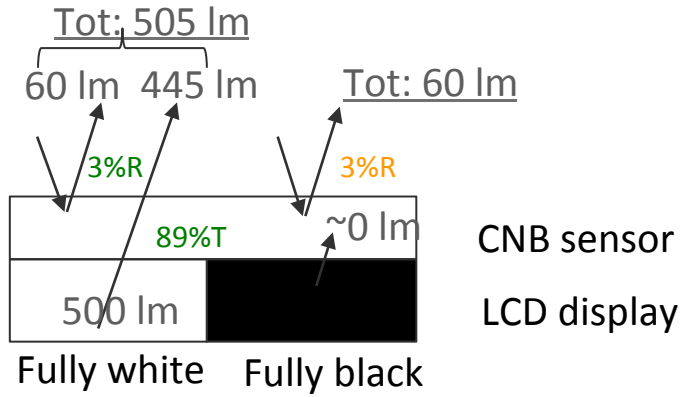
Compare contrast ratio between lit (ON) & unlit (OFF) areas of LCD display

Example:

- Display luminance 160 cd/m2 (e.g. 500 lm/m^2)
- Ambient illumination 2000 lux (e.g. 2000 lm/m^2, office in a sunny day)



Contrast ratio with ITO sensor: 4:1 (595:140)



Contrast ratio with CNB sensor: 8:1 (505:60)

Assumptions:

- ITO sensor transmission 91%, reflectivity 7%

Assumptions:

- CNB sensor transmission 89%, reflectivity 3%

CNB™ Sensors vs. ITO Sensors

CNB™ films reduce reflections and glare

GFF

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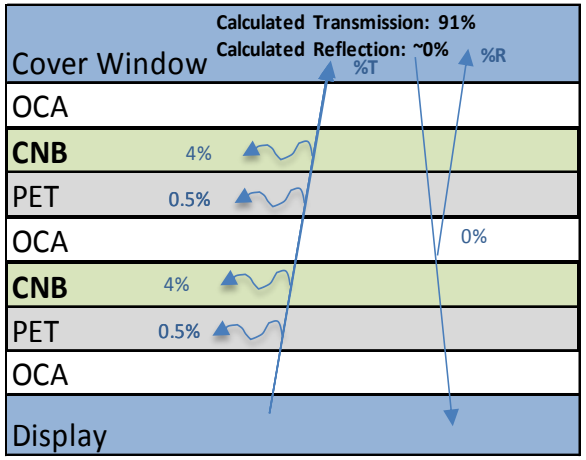
CNB™
R < 1%

GFF

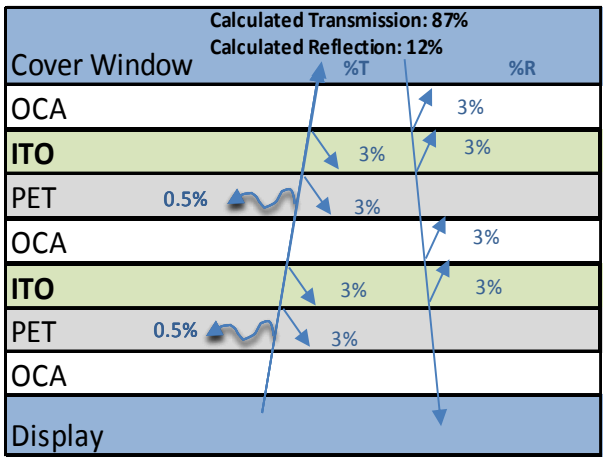
CNB sensor 150 Ω/□



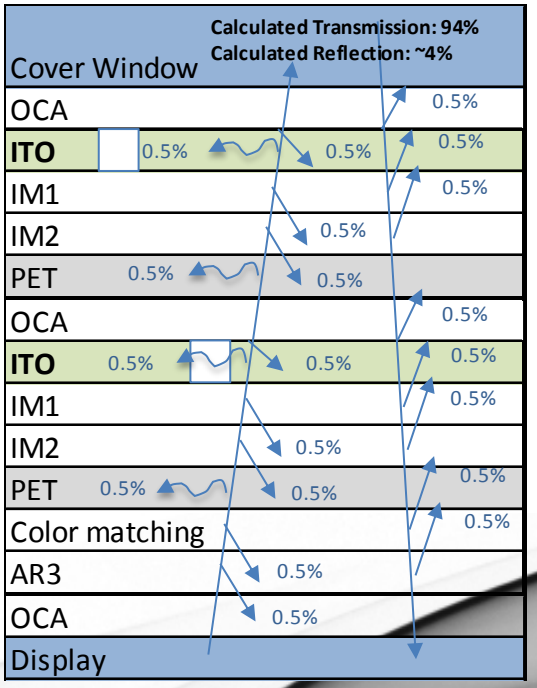
ITO
R = 12%

GFF

ITO sensor 150 Ω/□



ITO w. Index Matching
R = 4%



All devices (ITO or CNB) will typically have additional 1-4% reflection from the window front surface.

CNB Sensors Enhance Contrast
Visual Comparison

None (anti-glare)
CR = 6:1

High perf. ITO
CR = 3:1

Standard ITO
CR = 3:1

CNB
CR = 9:1

CR – Contrast near window: sunny day (~2000 lux)

- Bare display luminance 184 cd/m^2, CR=262:1 at dark.
- Laminated two-layer (G)FF sensors, PET substrate.

High Contrast of NanoBud® Touch Matters

Good display readability = positive user experience

Power savings

- Backlight largest power consumer in portable devices
- CNB sensor reduce backlight power and maintain same contrast as ITO sensor at full power
  - Increase battery life by 17% (Japanese customer study)

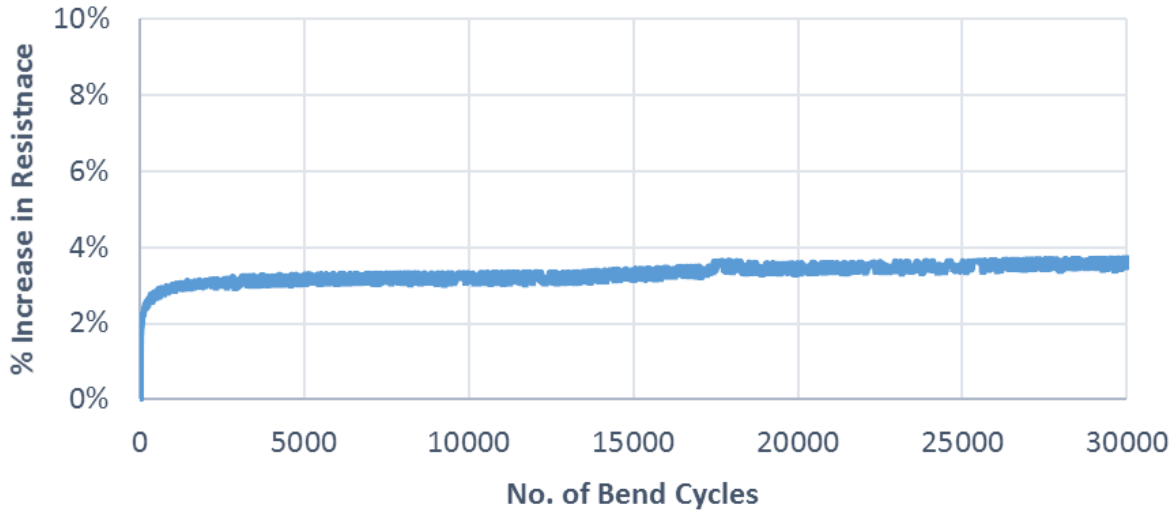
Cost reduction

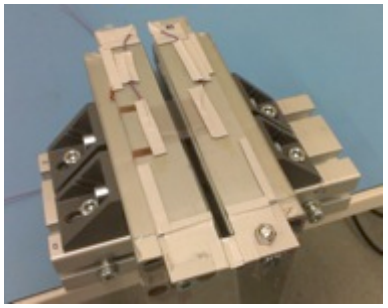
- Reduce the need for additional contrast enhancement films
- Reduce battery size
- Reduce need for structural support
- Reduce device size & weight

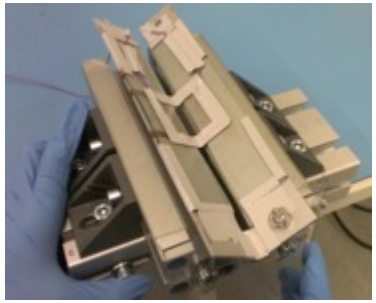
CNB™ Films are Extremely Flexible

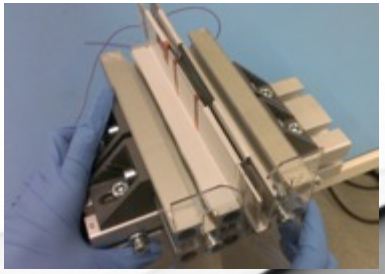
Less than 1% change at 2 mm bending radius

Less than 4% change at 1 mm bending radius



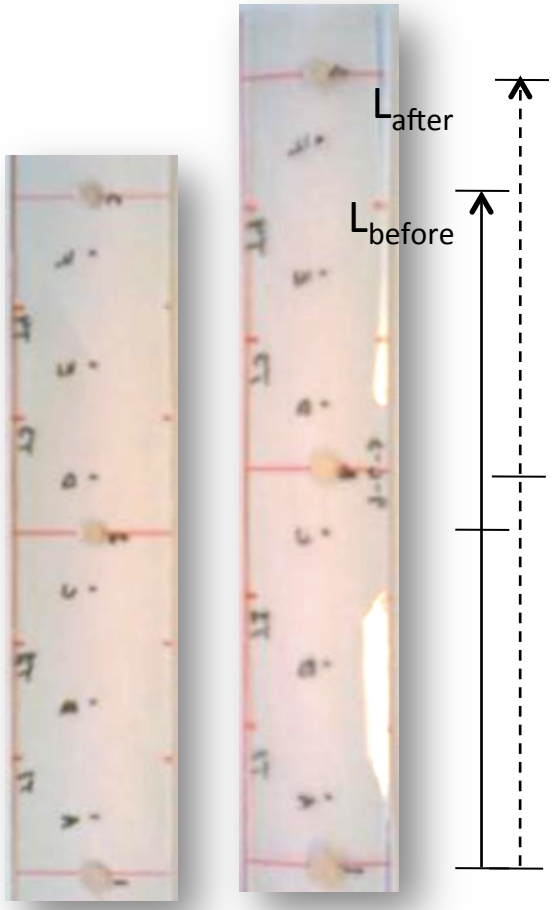


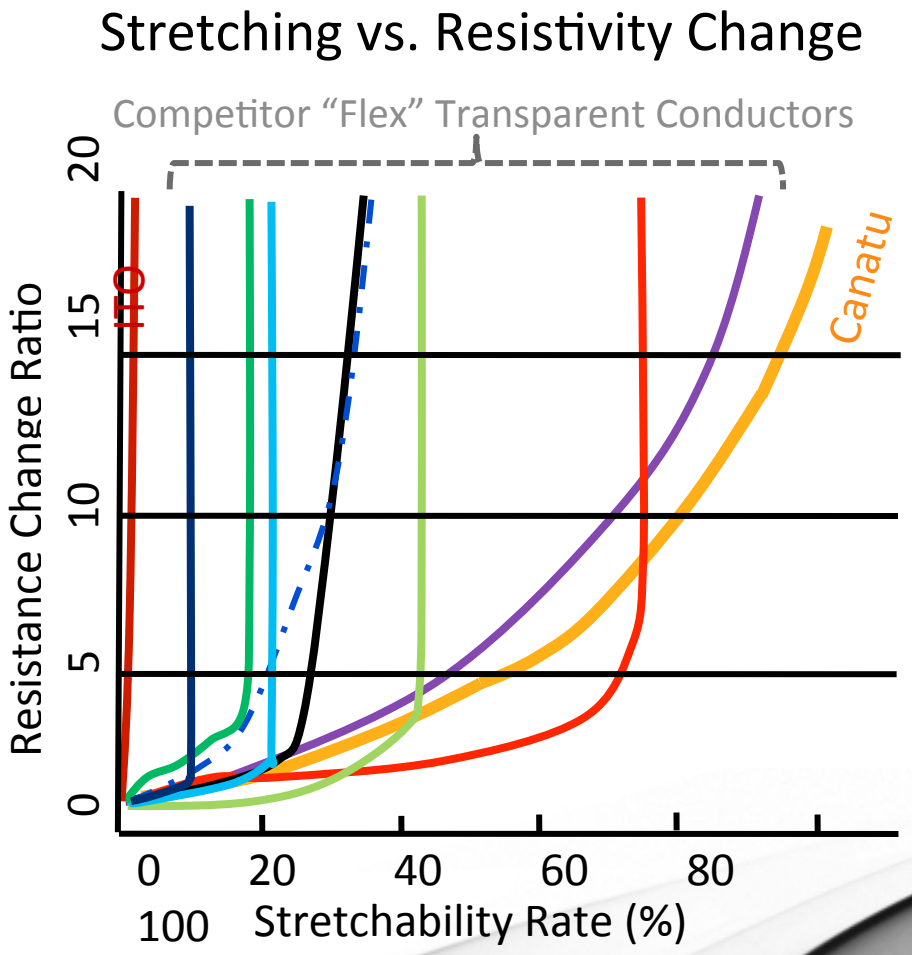




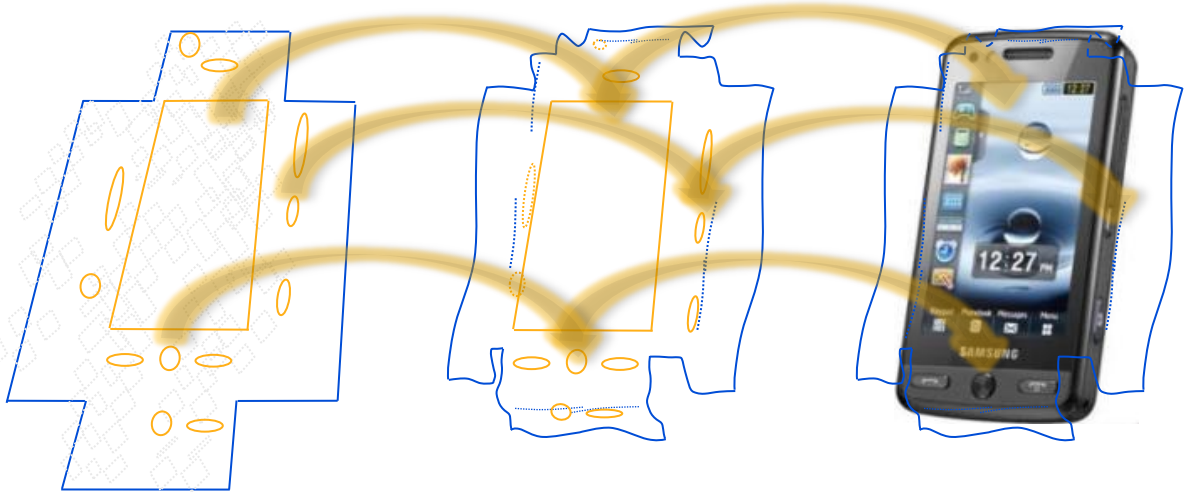
- 130 µm PET substrate
- CNB layer on inside bending side of substrate
- Change <1% after initial bends

Carbon NanoBud® are Highly Stretchabe





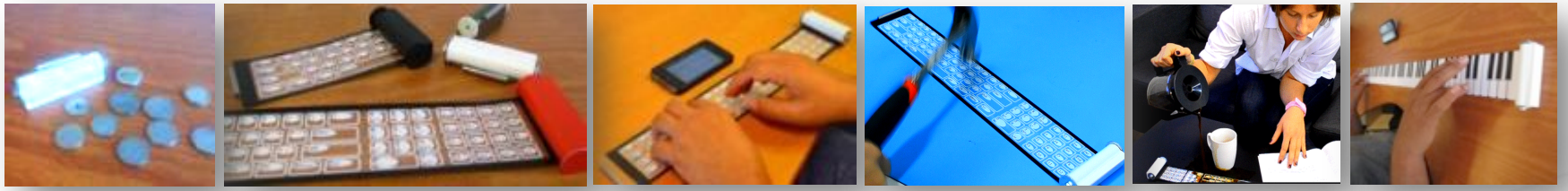
NanoBud® Films Enable New Forms and Functions



Stretchable Canatu Nanocarbon sensor

Thermoformed over display and phone casing

Replaces both touch screen and mechanical buttons



Rollable Canatu Nanocarbon sensor

Rolled into pocket sized casing

Provides a full-sized and pocket sized keyboard

NanoBud® Competitive Benchmarking

Carbon NanoBud® touch sensors enable excellent display appearance with elegant simplicity

		Carbon NanoBuds®	ITO on PET	Other CNTs	Silver nanowires	Metal meshes	PEDOT	Graphene
		Dry Process	Sputtered	Wet on PET	Wet on PET	Wet on PET	Wet on PET	
Electro-optical	Display appearance with touch sensor	High contrast: absorptive, no reflections	Low contrast: reflections	Dark: absorb too much light	Fuzzy image: hazy films	Visible pattern, Moiré	Hazy and blueish	
	Transmittance for 150 ohm/sq film (through PET substrate in touch sensor)	95%	~95%	~85%	~95%	~95%	~90%	~90%
	Refractive index	~1.6	>2	~1.6			~1.6	~1.6
	Haze	~0.3%	≥1%	<1%	~2%		~1%	
	Color neutrality	neutral	yellowish	neutral	yellowish	reddish	blueish	
Environmental &Mechanical	Thermal stability							
	Humidity stability							
	Bendability / Foldability	<<0.5 mm radius						
	Stretchability / Thermoformability		cracks					
	Environmental Impact	organic	mining		destroys biolog. cells			
Production	Process Simplicity	dry process	complex etching	difficult printing	difficult printing	need anneal		
	Product Simplicity	simple stack	needs IM, AR			aliasing		
	Ready for industrial production							
	Potential for further improvement							
	Cost of patterned 150 ohm/sq film							

Best | Good | Average | Bad | Worst

Canatu Touch Business Model

OEM / Brand Customer

EMS Integrator

Touch Module

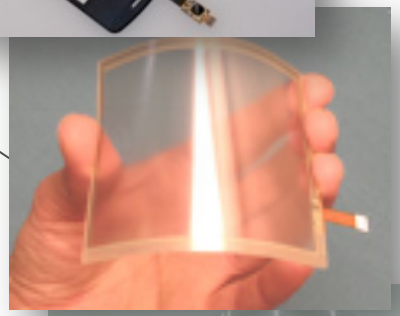
CanaTouch™
Controller IC

Canatu's CNB Capacitive Sensor

Connector, flex cables etc.

Ag traces
CNB
PET

High volume: CNB Film



Low volumes: CNB Sensors

Disclosable Partners

intel

SMK

ALPS
ALPS ELECTRIC GROUP

ATMEL

Canatu's unique selling points

Existing Products

Improve performance

- Look
  - (Better color, brightness, contrast, readability)
- Ruggedness
  - (Improved shock, environment)
- Usability
  - (longer battery life, less weight)

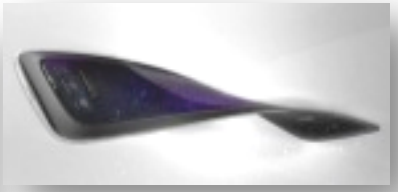
Lower cost

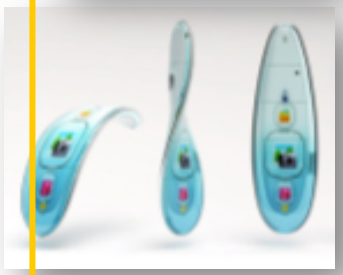
- Simpler components and supports
- Cheaper, greener materials/process
- Higher yield / shorter supply chain

New Products

Enable new design possibilities

- Flexibility, bendability, formability
- 3D, twistable, rollable, foldable
- Touch anywhere on anything

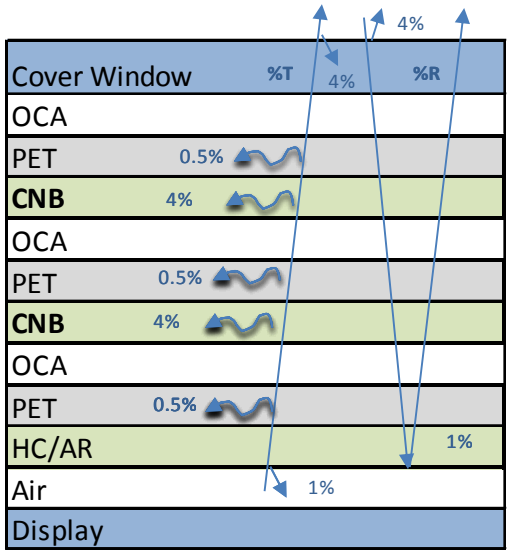






Example: GFF Sensor in 13.3” Laptop

Large Area with High Contrast and Invisible Patterns

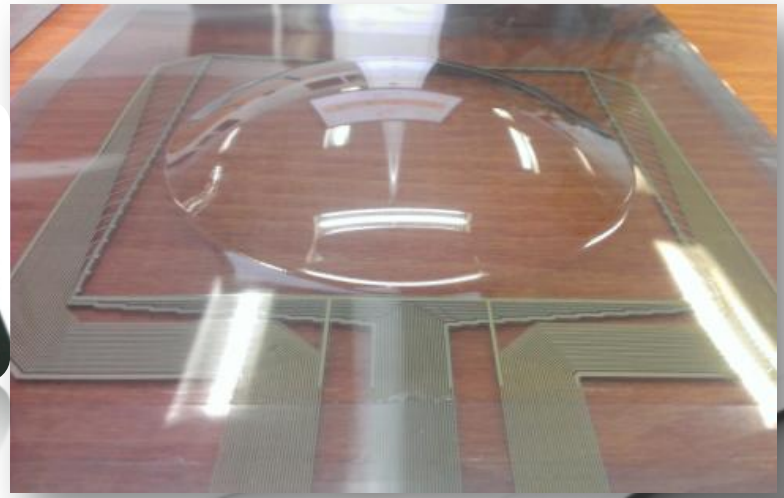
- Demonstrator for 13.3” Windows 8 Ultrabook
  - Totally invisible patterns
  - Reflections from Module ~5%, transmission ~85% (Gen 4)
    - Reference OGS ITO module reflection is 10% (2x higher)
  - High contrast touch display in Ultrabook
    - CNB version has 30% higher contrast than OGS ITO version
  - 10 finger multi-touch, no ghost positions
  - Windows 8 compatible



Example: NanoBud® Sensor in 3D Form
Multi-touch with invisible patterns

- Demonstrator of 3D shaped ProCap sensor
  - 12 cm diameter, thermoformed to 15 cm curvature
  - Transmission through active CNB layers >97%
  - Totally invisible patterns
  - 10 finger multi-touch, no ghost positions
  - Resolution: 254 dpi (10 pixels per mm)
  - Touch point separation: 10 mm center-to-center
  - Report interval: 12ms

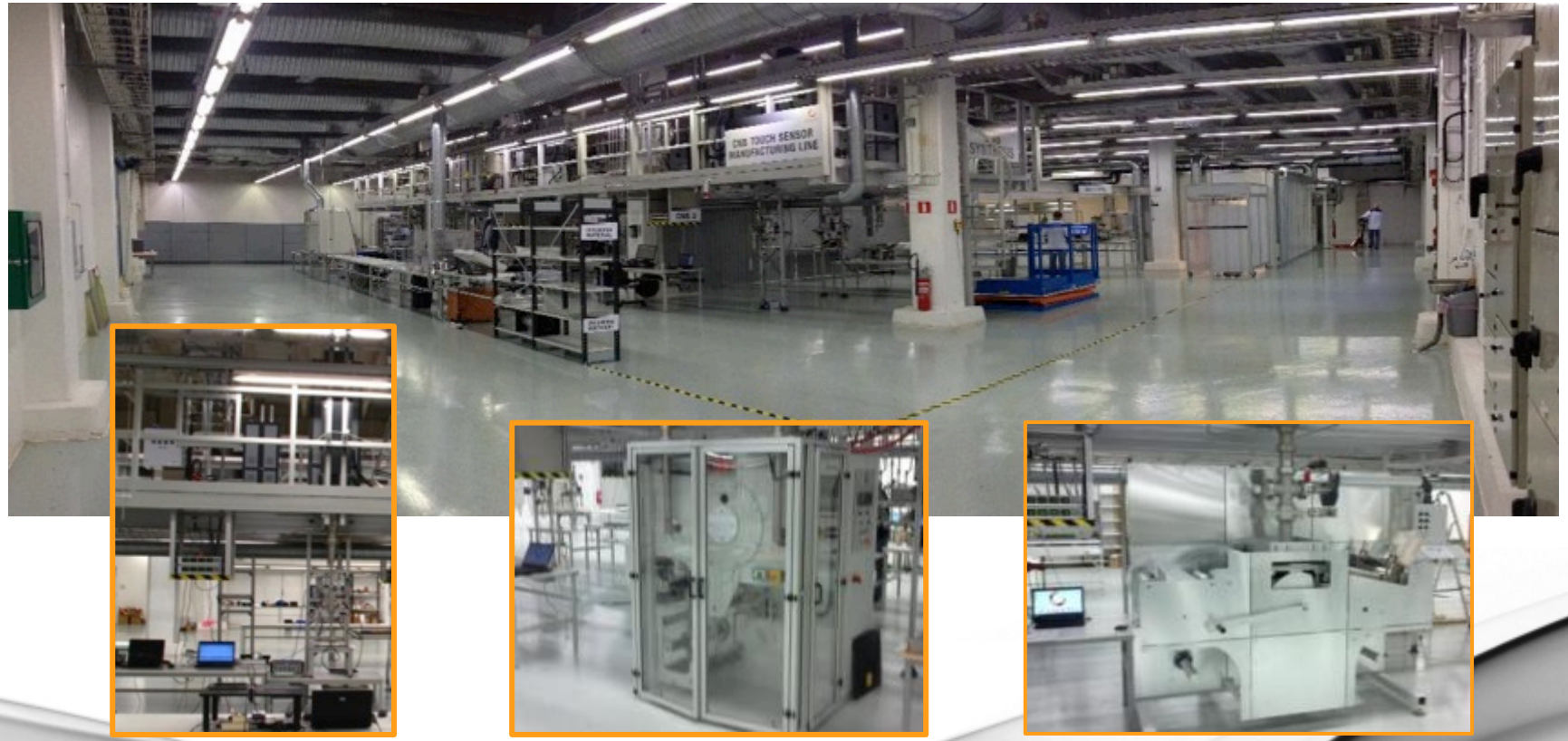
I-Zone



Canatu's Production Facility

In Helsinki, Finland
Customer prototype production started
Installed reactor capacity for medium size customer demand

1200 m^2 production space
400 m^2 clean room
300 m^2 office space



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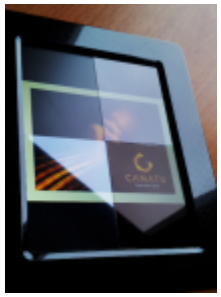
Why use Carbon NanoBud® touch sensors?

1) Allow Flexible and 3D forms



2) Improve Display Appearance

2) Save Power, Size and Weight

3) Reduce Cost and Complixity

4) Be “Green”

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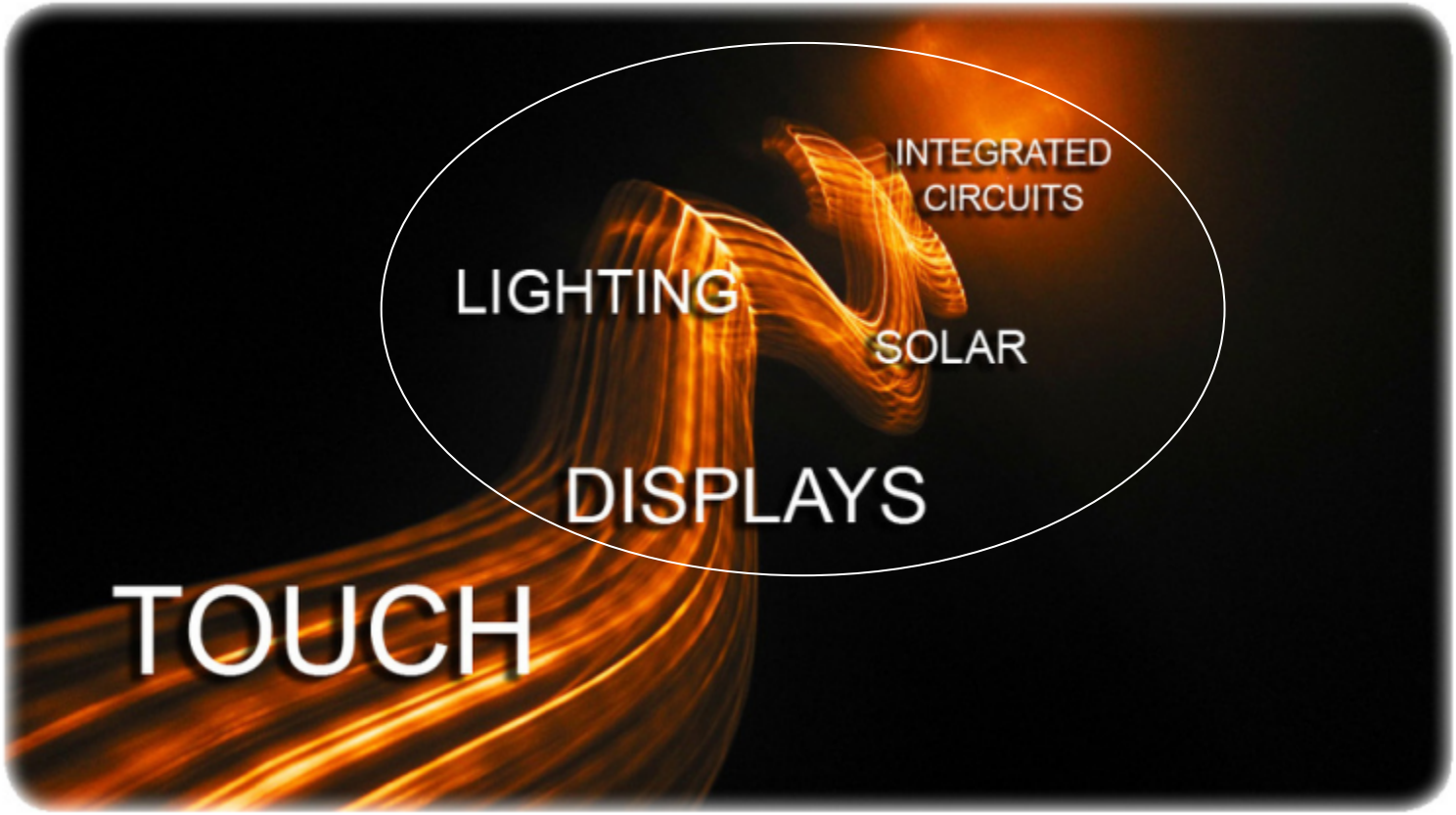
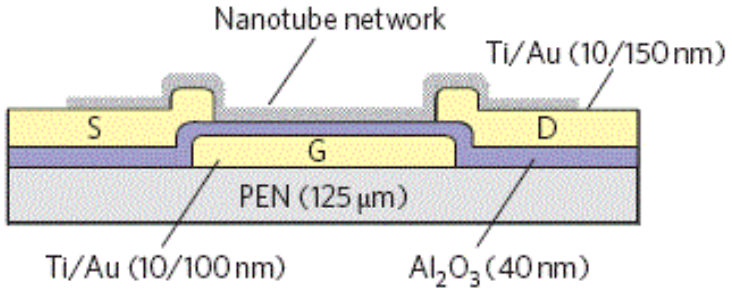
Canatu's product roadmap

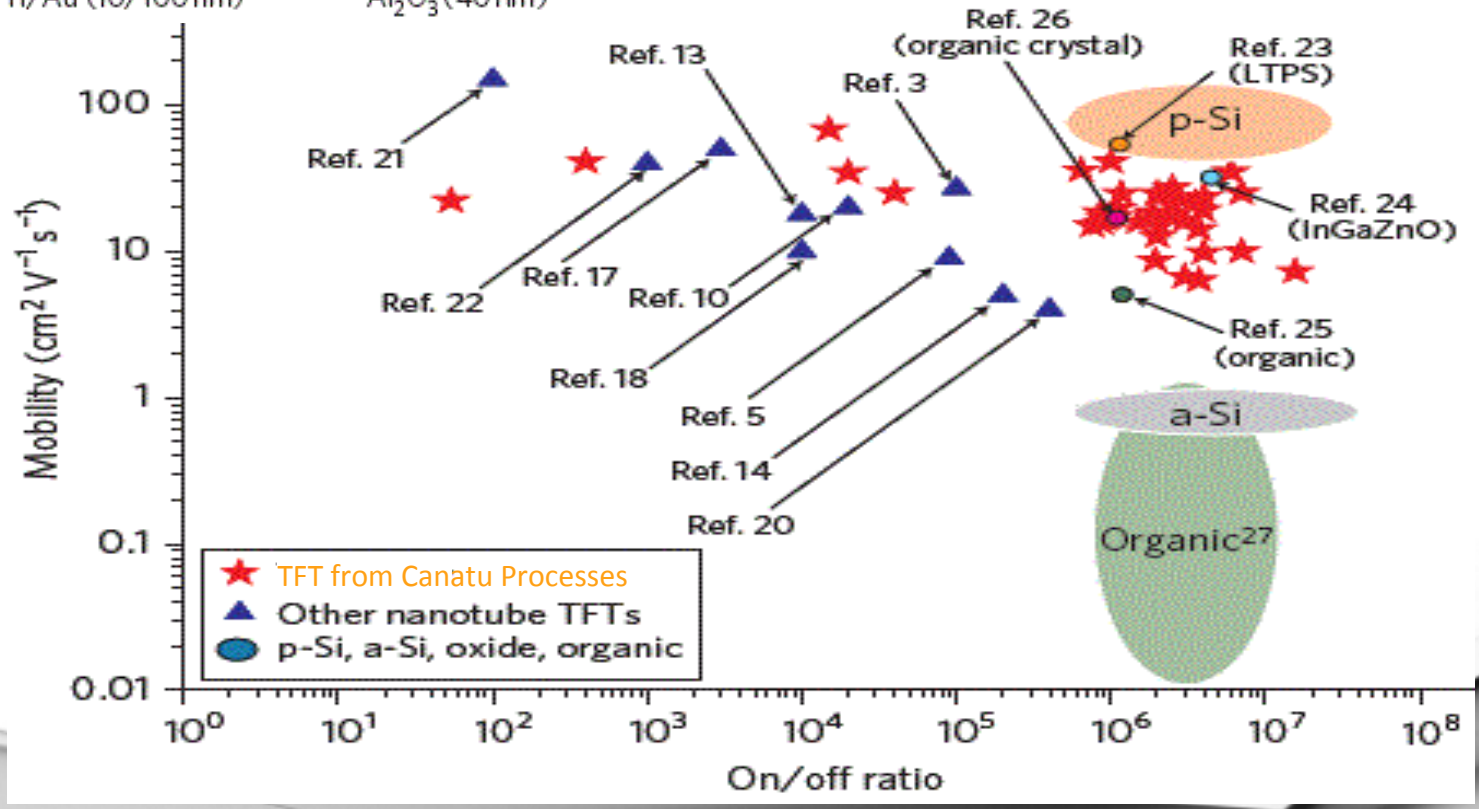


- Canatu's films are useful in numerous additional products
- Enable new device structures, shapes and functions

Thin Film Transistor (TFT): *On/off = 6x10^6, mobility = 35 cm^2/(V*s)*

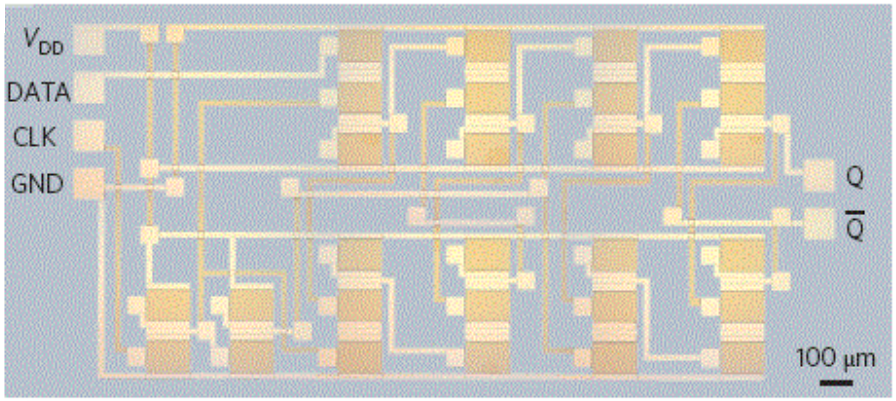


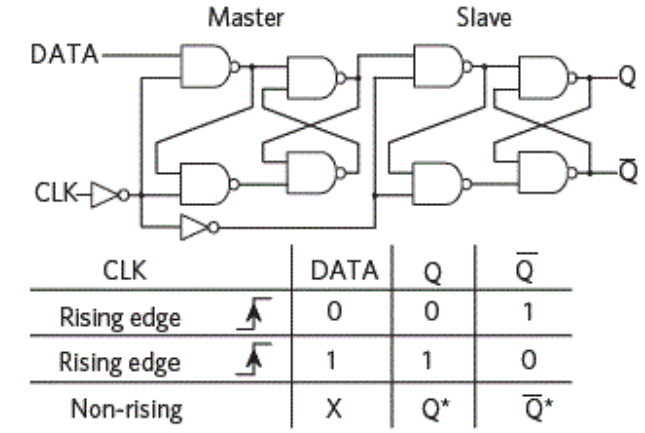
Sun et al., (2011)
Nature *Nanotechnology DOI: 10.1038*



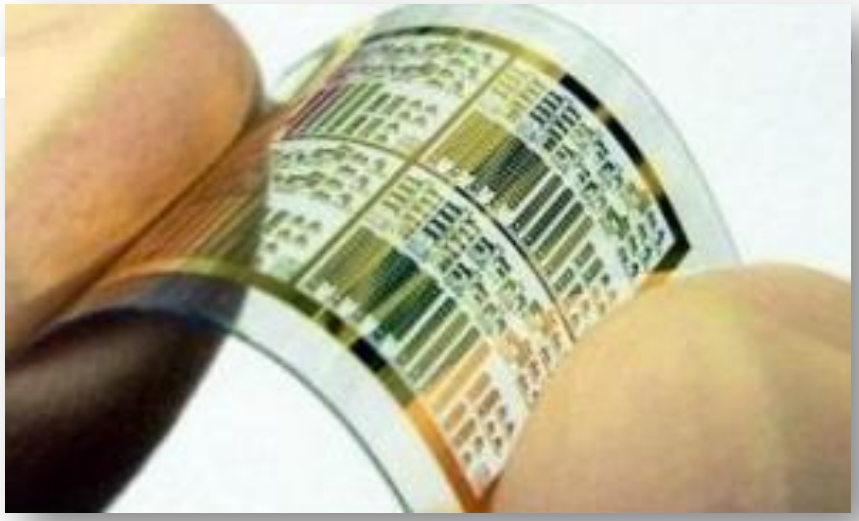
World's 1st Dry Printed-TFT Synchronous Sequential Logic Circuits

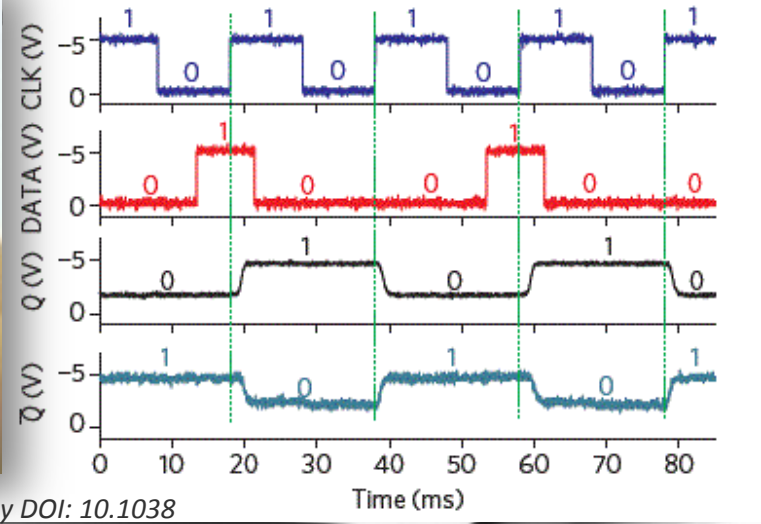
Logic Gates & Delay Flip-Flops on Flex Substrates by Direct Dry Printing ®





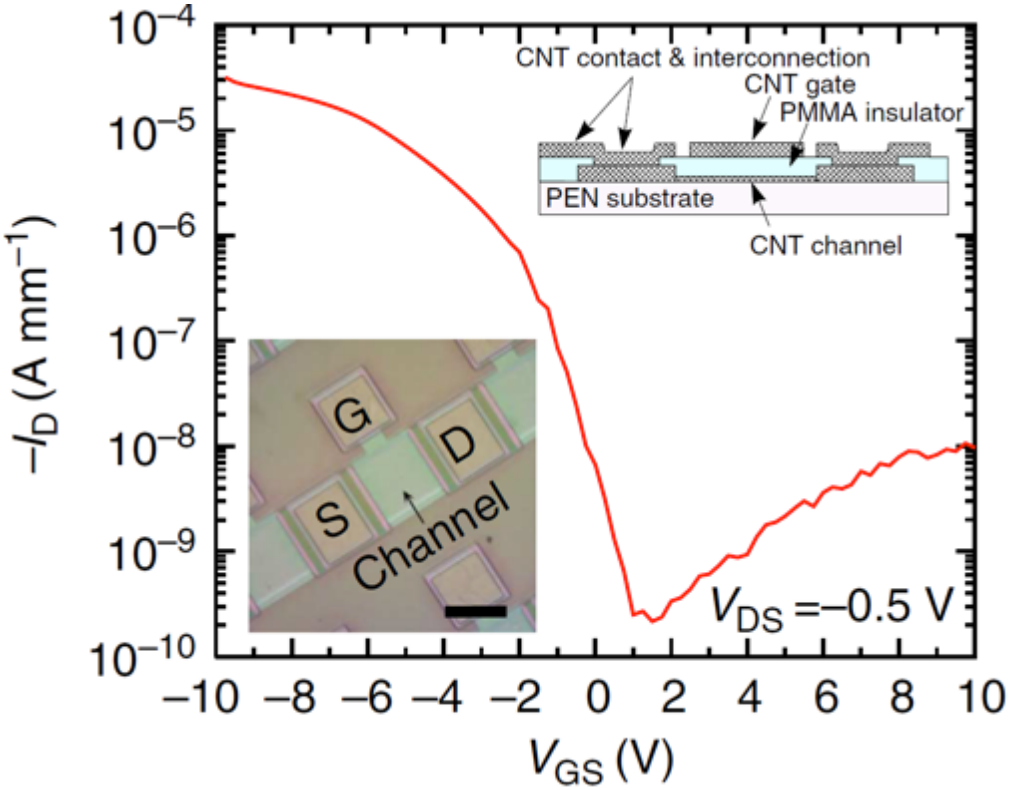
CLK	DATA	Q	$\overline{Q}$
Rising edge ↑	0	0	1
Rising edge ↑	1	1	0
Non-rising	X	Q*	$\overline{Q}$*

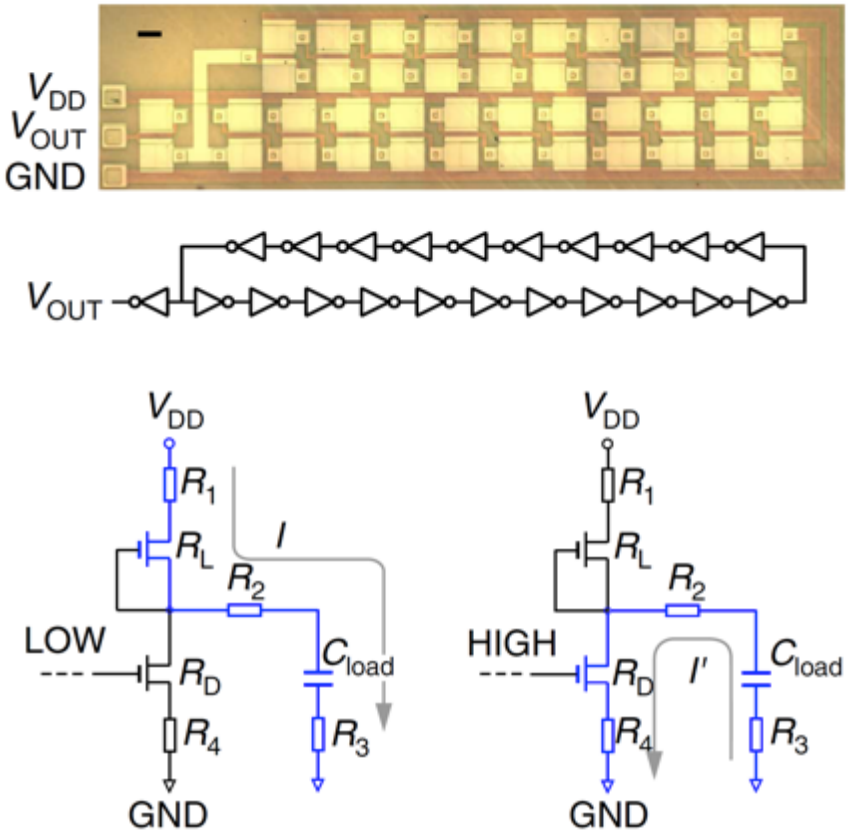




Sun et al., (2011) Nature *Nanotechnology DOI: 10.1038*

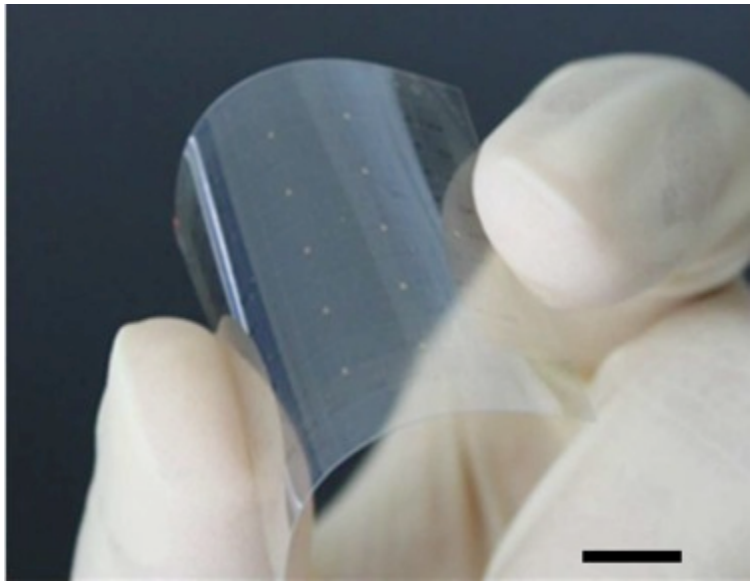
World's 1st All-Carbon TFT

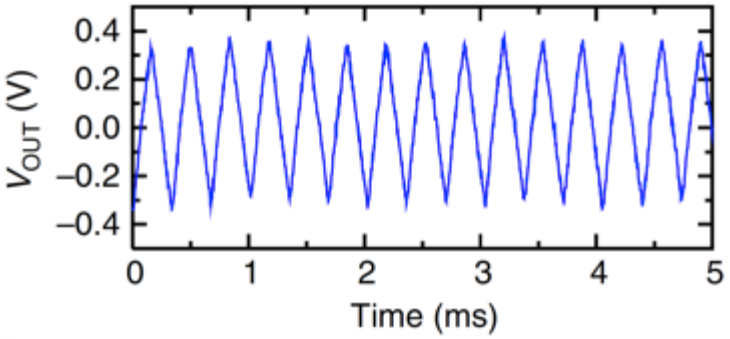


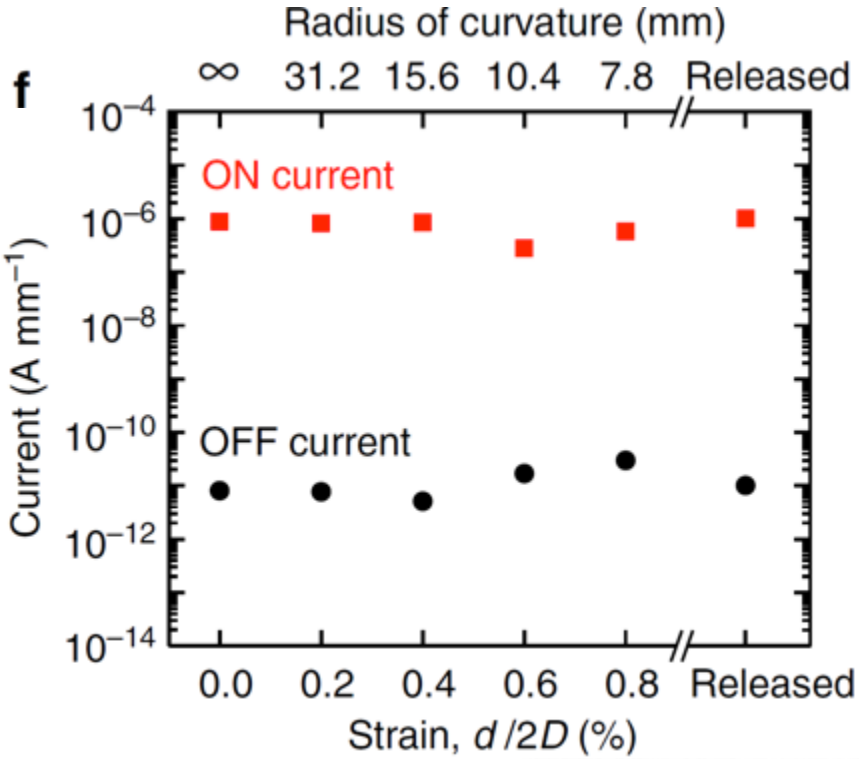


Sun, Nasibulin, Kauppinen et al., (2013) Nature *Communications 4:2302 DOI: 10.1038/ncomms3302*

World's 1st Flexible All-Carbon TFT

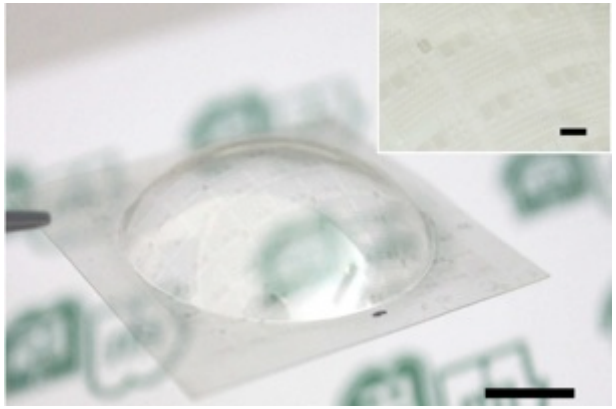


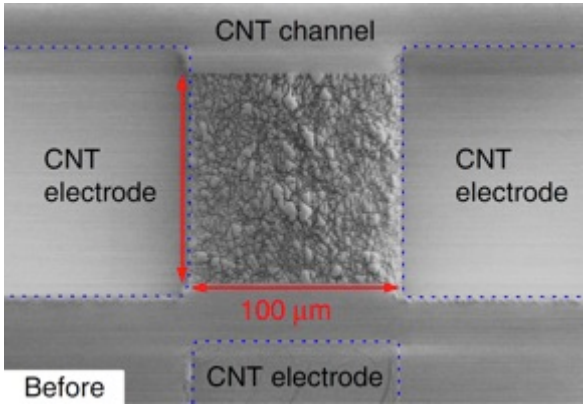


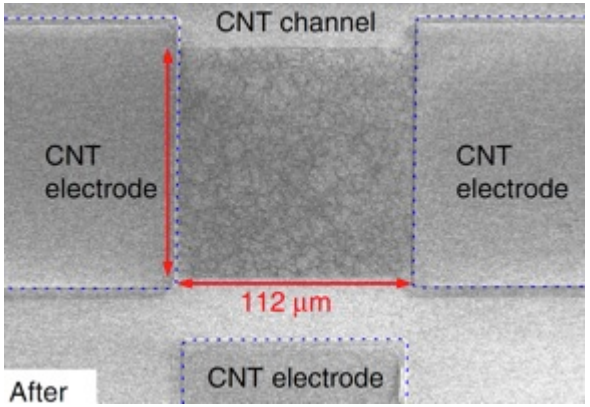


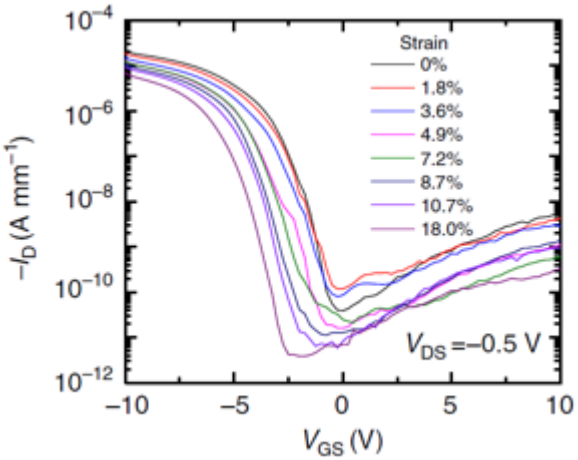
Sun, Nasibulin, Kauppinen et al., (2013) Nature *Communications 4:2302 DOI: 10.1038/ncomms3302*

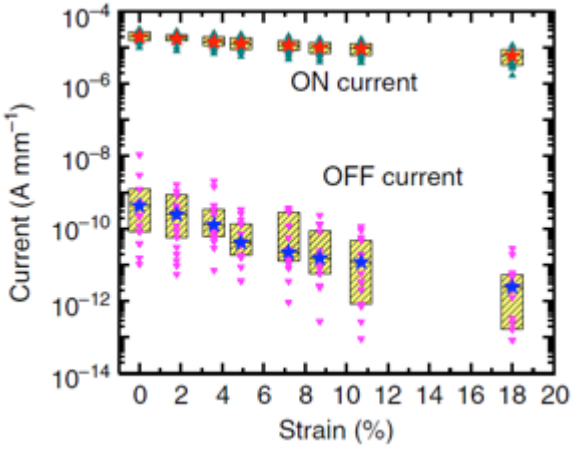
World's 1st Moldable All-Carbon TFT

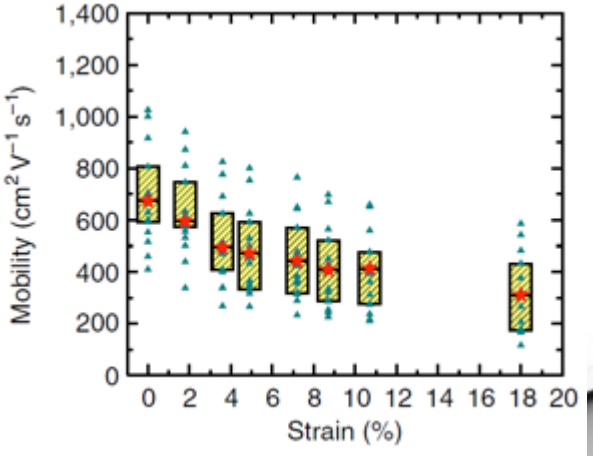












Sun, Nasibulin, Kauppinen et al., (2013) Nature *Communications 4:2302 DOI: 10.1038/ncomms3302*

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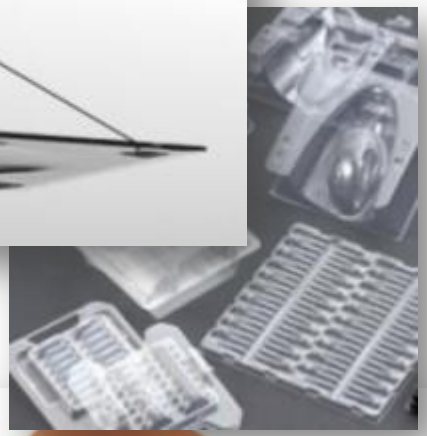
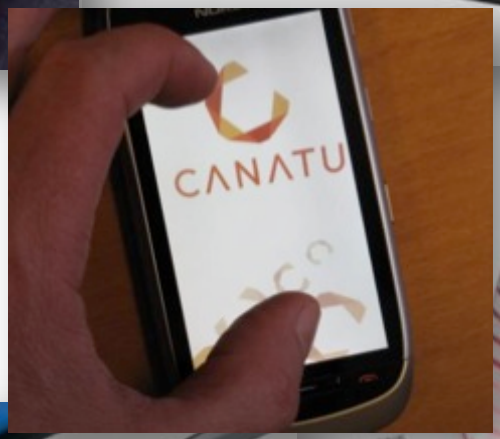
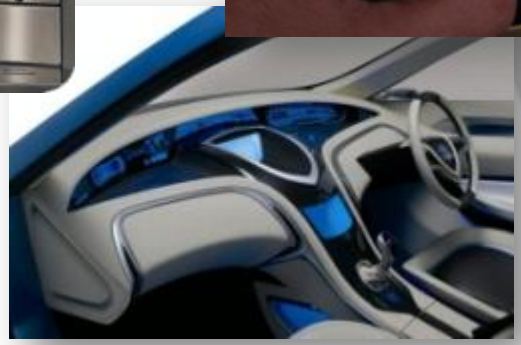
Canatu – Touch the Future

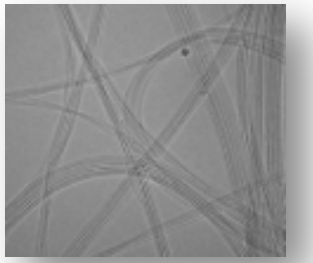






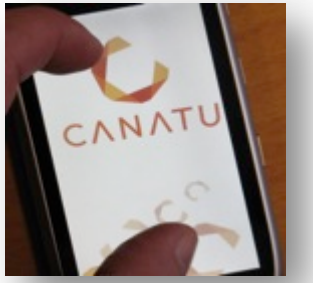
Summary

Canatu: Leading in innovation & hungry for growth



NanoBud® films: Excellent optical performance & simplicity for flexible, stretchable, bendable & formable applications

Canatu's touch sensors: Flexible, clear & elegantly simple



Canatu is building the manufacturing & supply chain now to enable the touch of the future

Canatu will be a key enabler for flexible electronics: display electrodes & backplanes, OLED lighting, PV etc.

CANATU

Touch the Future

Thank You!

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CNB™ films are stable

Passing standard environmental tests

Test	Specification	Result				
		ΔRs (Sheet resistivity change)	Δ%T (Transmission change)	ΔHaze	ΔE (Color change)	Adhesion
Room temperature storage	25°C/60% RH for 240 h	**<10%**	**<0.5%-units typ**	**<0.2%-units typ**	**ΔE < 1**	**Passed**
Constant Temperature/ Humidity storage	IEC 68-2-78 (IEC 68-2-3) 60°C/90% RH for 240 h	**25% typ**	**<1.5%-units typ**	**<0.25%-units typ**	**ΔE < 1**	**Passed**
Thermal Cycle storage	IEC 68-2-2, IEC 60068-2-14 Test N, IEC 60068-2-14 Na, -40°C (0.5h)/ +85°C (0.5h) for 50 and 200 cycles.	**<10%**	**<1%-units**	**<0.2%-units typ**	**ΔE < 0.5**	**Passed**
High Temperature storage	IEC 68-2-2, IEC 60068-2-2 Dry heat tests, 85°C for 240 h	**<15%**	**<1% units**	**<0.2%-units**	**ΔE < 0.5**	**Passed**
Low Temperature storage	IEC 68-2-1 -40°C for 240 h	**<4%**	**<0.2% units**	**<0.3%-units**	**ΔE < 0.5**	**Passed**

$$\Delta E = \sqrt{(L_2 - L_1)^2 + (a_2 - a_1)^2 + (b_2 - b_1)^2}$$

Results from plain CNB™ films (i.e. not in touch stack).