Solid State Devices
Section 1: Introductions

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nanoHUB

Solid State Devices

Section 1: Introductions

Section 1.1 Why are they interesting?

Learning Objectives

Solid State Devices => Nanotechnology

Changed Human History

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https://en.wikipedia.org/wiki/Control_of_fire_by_early_humans

Solid State Devices

Why are they interesting?

Solid State Devices => Nanotechnology Changed Human History

iPad 2

(2011)

Solid State Devices

Why are they interesting?

Solid State Devices => Nanotechnology Changed Human History

Cray 2

World's fastest supercomputer in 1985

=

4 GFLOPS

iPad 2

(2011)

You hold a 1980's supercomputer …… in your hands…

https://www.phoronix.com/scan.php?page=news_item&px=MTE4NjU

http://s3data.computerhistory.org/brochures/cray.cray2.1985.102646185.pdf

Solid State Devices

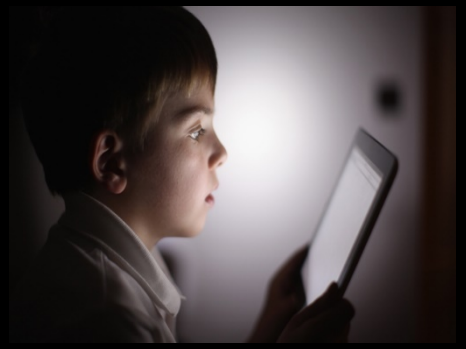
Why are they interesting?

Solid State Devices => Nanotechnology
Changed Human History

Chille
Custom acces

5,500 lbs – 2,475kg
195 kW

=
4 GFLOPS



iPad 2
(2011)

Mobile
Taken along to Space Station

1.3 lbs – 0.585kg
5 W

$4x10^3$ smaller
$4x10^4$ smaller

You hold a 1980's supercomputer …… in your hands…

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http://s3data.computerhistory.org/brochures/cray.cray2.1985.102646185.pdf
https://www.computerhistory.org/revolution/supercomputers/10/68
https://en.wikipedia.org/wiki/IPad_2

Solid State Devices

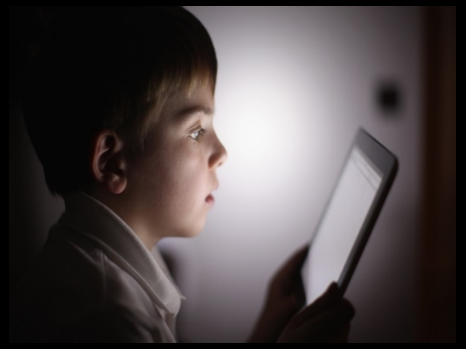
Why are they interesting?

Solid State Devices => Nanotechnology

Changed Human History

=

4 GFLOPS

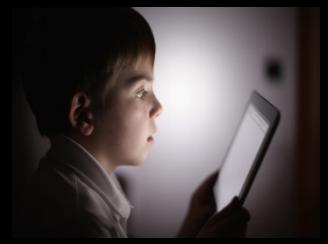


Cray 2		iPad 2	
World's fastest supercomputer in 1985		(2011)	
Chilled water cooling + custom room		Mobile	
Custom access - special user training		Taken along to Space Station	
5,500 lbs – 2,475kg		1.3 lbs – 0.585kg	$4x10^3$ smaller
195 kW		5 W	$4x10^4$ smaller
$M 12-17		$500-700	$2x10^4$ smaller
27 units sold		>1M sold first weekend ~35M sold in 1 year	$1x10^6$ larger

You hold a 1980's supercomputer …… in your hands…

Solid State Devices

Modern society runs on nanotechnology…



- Communications
- Any business operation
- Any manufacturing
- Agriculture

Solid State Devices => Nanotechnology
Changed Human History

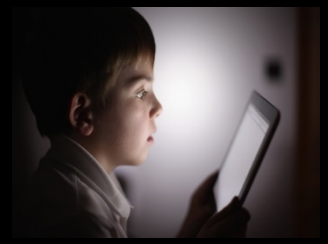
$4x10^4$ smaller

$1x10^6$ larger

https://rainrfid.org/wp-content/uploads/2018/03/IDTechEx-RFID-March-_Distribute.pdf

Solid State Devices

Modern society runs on nanotechnology…



- Communications
- Any business operation
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- Agriculture

Solid State Devices => Nanotechnology Changed Human History

RFID tags Secure financial transactions

$4x10^4$ smaller

$1x10^6$ larger

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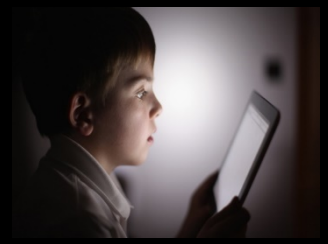
Solid State Devices

Modern society runs on nanotechnology…



- Communications
- Any business operation
- Any manufacturing
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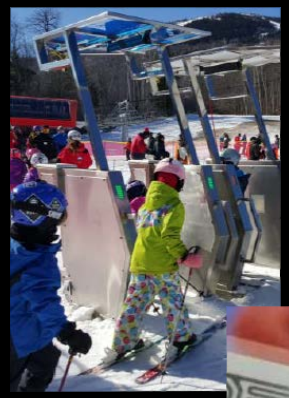
Solid State Devices => Nanotechnology
Changed Human History

RFID tags



Secure financial transactions

Short term use commodity

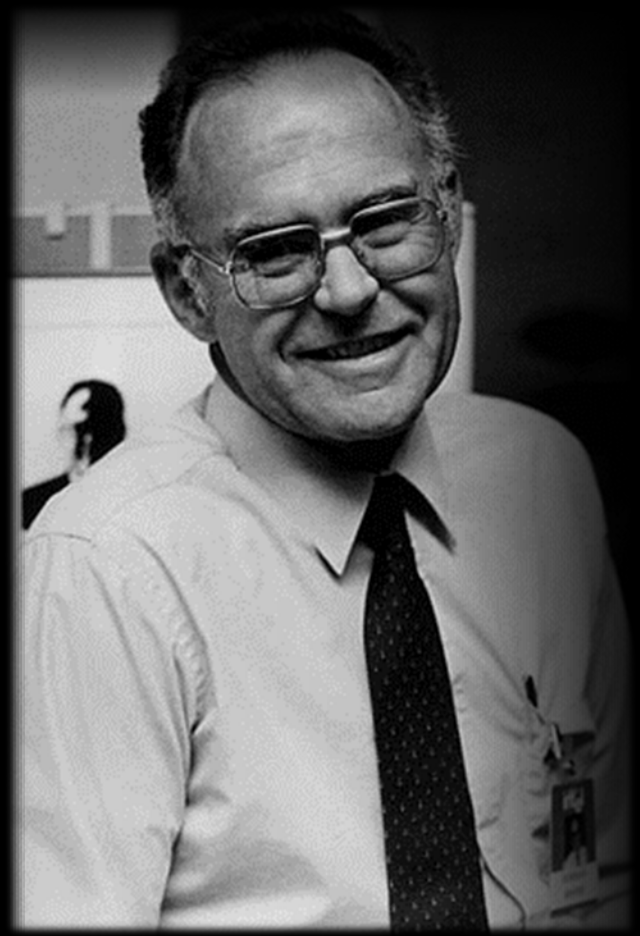
76 Billion sold in 2018

$4x10^4$ smaller

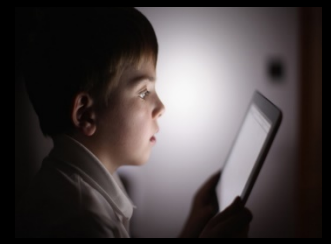
$1x10^6$ larger

https://rainrfid.org/wp-content/uploads/2018/03/IDTechEx-RFID-March-_Distribute.pdf

1965 – Gordon Moore predicts the future of integrated circuits



Relative Manufacturing
Cost per Component



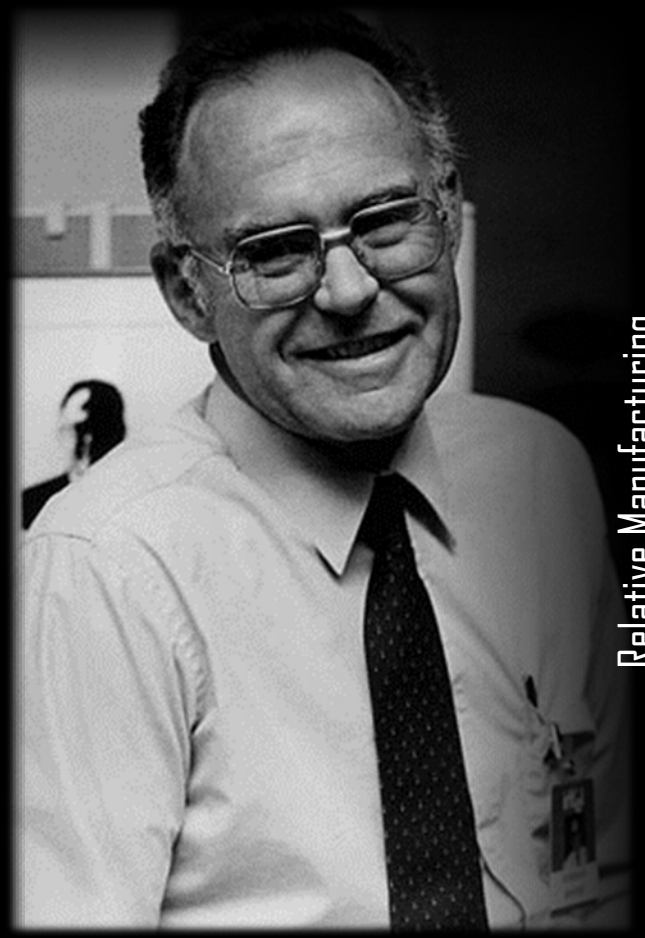
Number of Components per Integrated Circuit

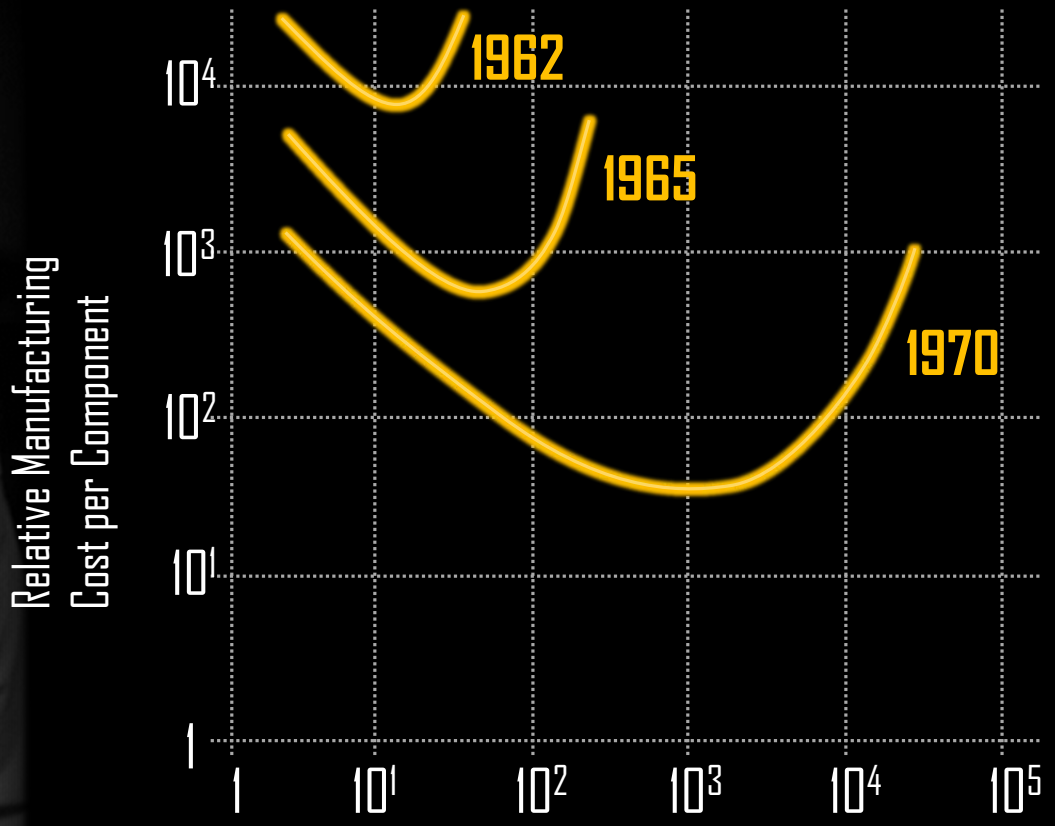
$4x10^4$ smaller

$1x10^6$ larger

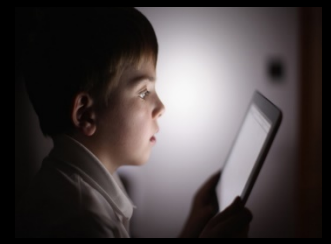
Changed Human History

1965 – Gordon Moore predicts the future of integrated circuits





http://www.intel.com/technology/mooreslaw



10^9

$4x10^4$ smaller

$1x10^6$ larger

Changed Human History

The number of transistors per chip doubles about every two years

1 billion
100 million
10 million
1 million
100,000
10,000
1000

1970
1975
1980
1985
1990
1995
2000
2005
2010
2015

10^9

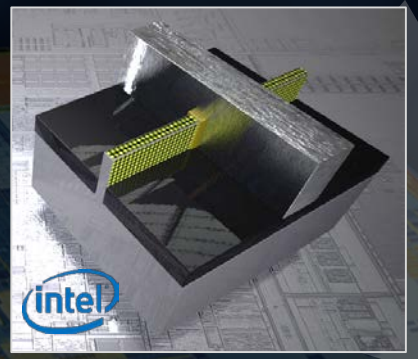
$4x10^4$ smaller

$1x10^6$ larger

Changed Human History

The number of transistors per chip doubles about every two years

22 nm Tri-Gate Transistor



Humans on Earth

10 billion

10^9

2019

1 billion

100 million

10 million

1 million

100,000

10,000

1000

1989

Intel 486 processor

1.2 million transistors

Intel 286

134,000 transistors

Intel 8080

4,500 transistors

Intel 4004

2,300 transistors

2000

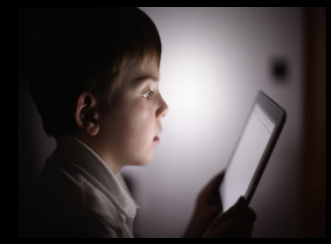
Intel Pentium 4

42 million transistors

2012

3rd gen. Intel Core

1.4 billion transistors

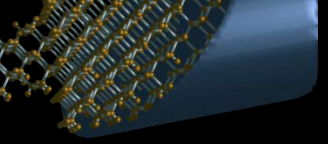


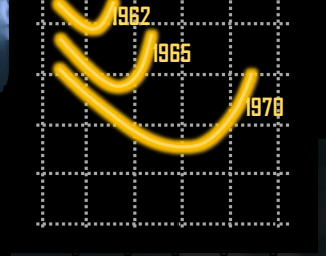
$4x10^4$ smaller

$1x10^6$ larger

Changed Human History

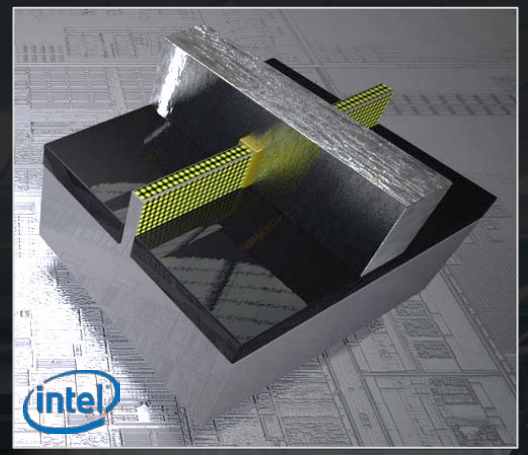
1970 1975 1980 1985 1990 1995 2000 2005 2010 2015





Production Cost Reduction
Size Reduction

22 nm Tri-Gate Transistor

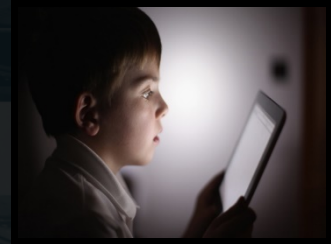


1
0.1
0.01
0.001

$ / Transistor
(relative to 0.35um)

Transistor node size

.35um .25um .18um .13um 90nm 65nm 45nm 32nm 22nm 14nm 10nm



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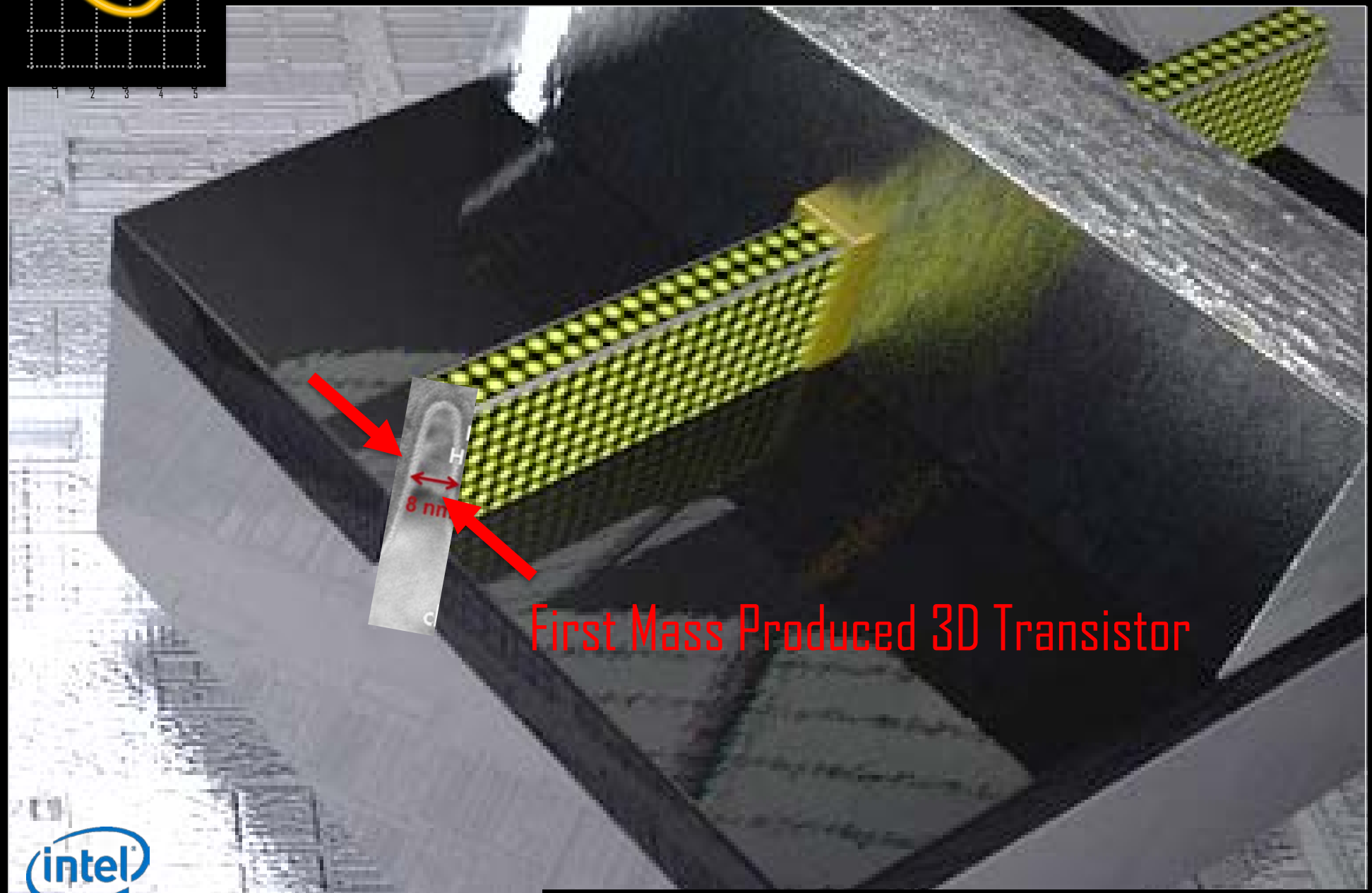
Changed Human History

22 nm Tri-Gate Transistor



http://www.chipworks.com/media/wpmu/uploads/blogs.dir/2/files/2012/08/Intel22nmPMOSfin.jpg

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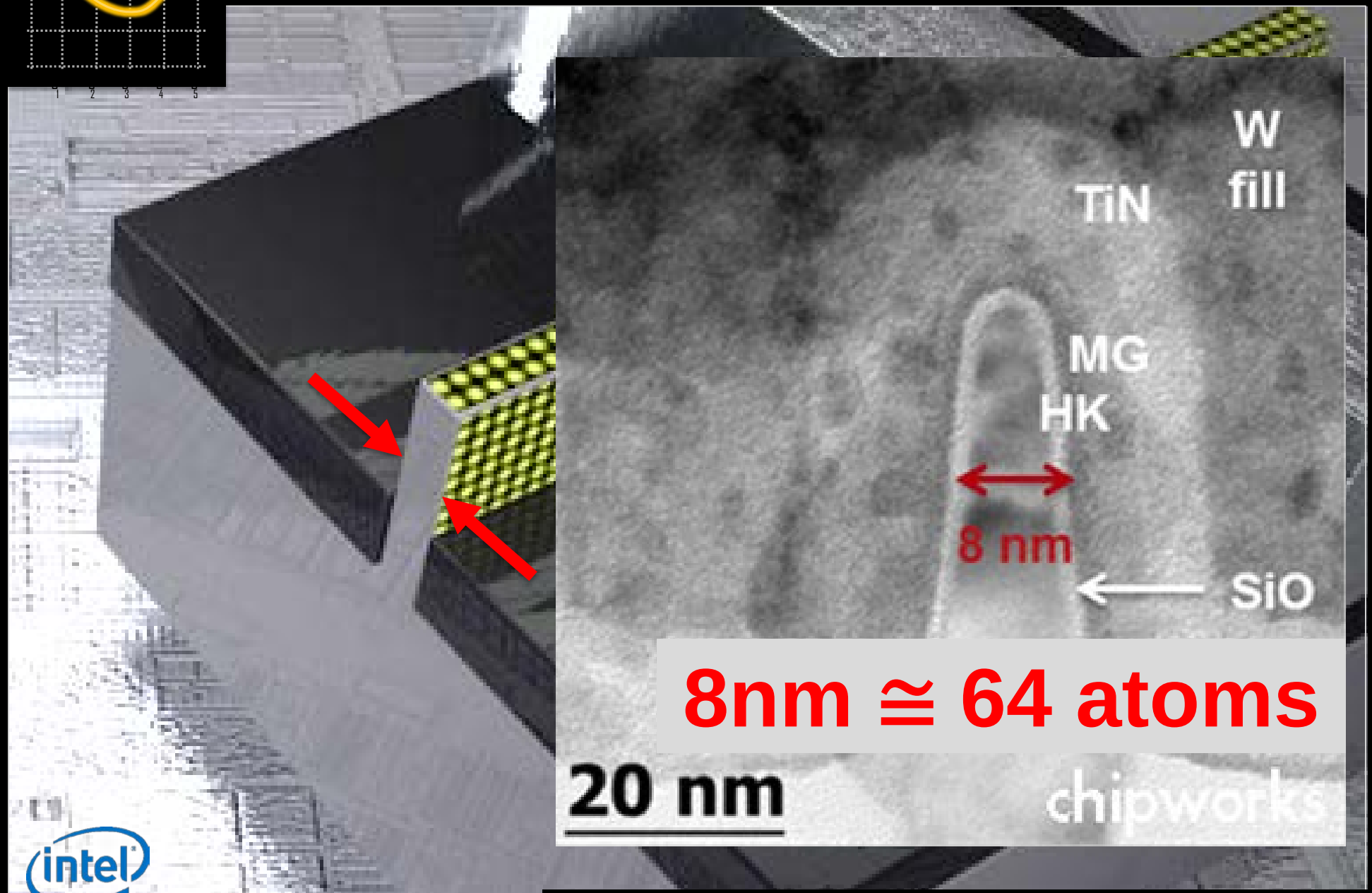

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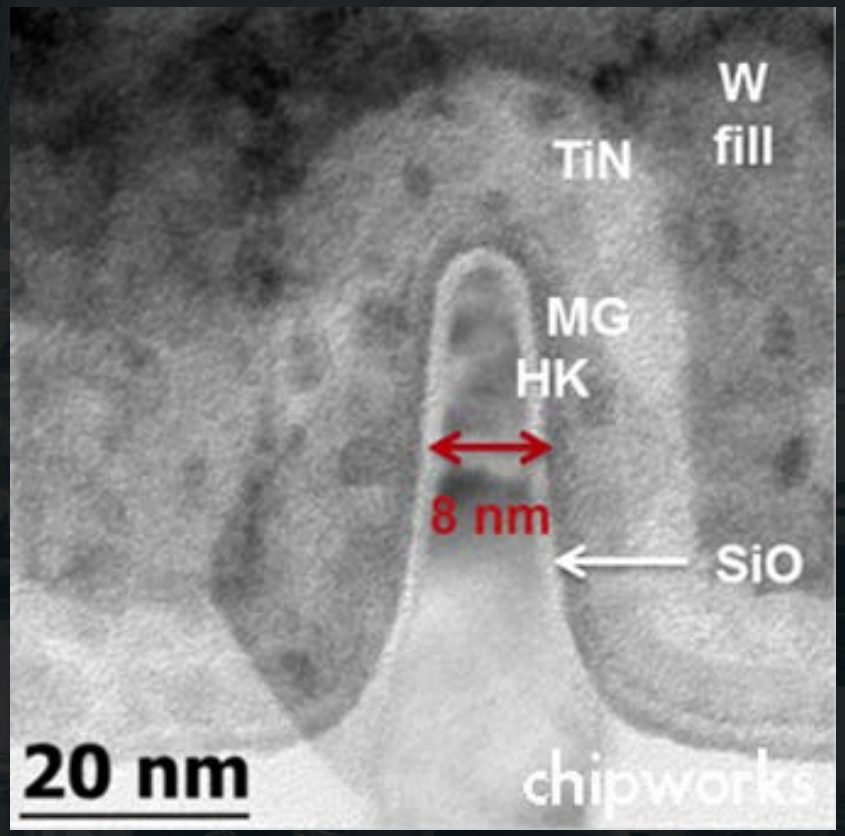
Devices are Atomically Small

22 nm Tri-Gate Transistor



8nm ≅ 64 atoms

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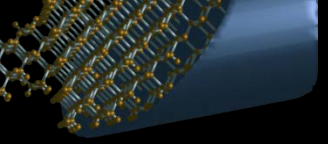
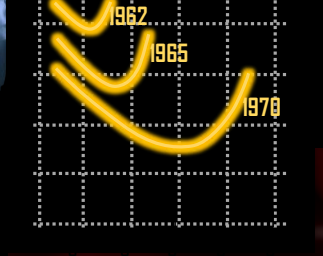
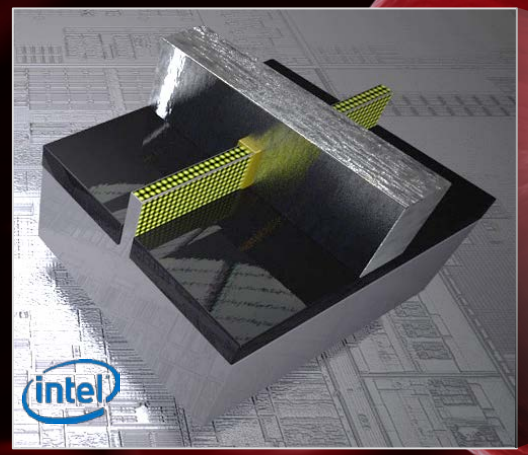




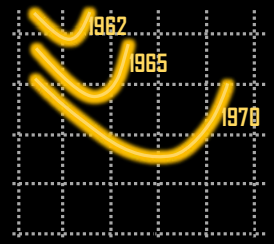
Devices are Atomically Small

22 nm Tri-Gate Transistor



Red blood cell
d = 7,000 nm

Costs of 66 different technologies over time, 1930 to 2013



Wind Turbine (Denmark)

Milk (US)

PolyesterFiber

Automotive (US)

Refined Cane Sugar

Transistor

100,000
10,000
1,000
100
10
1
0.1
0.01
0.001
0.0001
0.00001
0.000001
0.0000001

1930 1940 1950 1960 1970 1980 1990 2000 2013

Our World in Data

https://ourworldindata.org/technological-progress

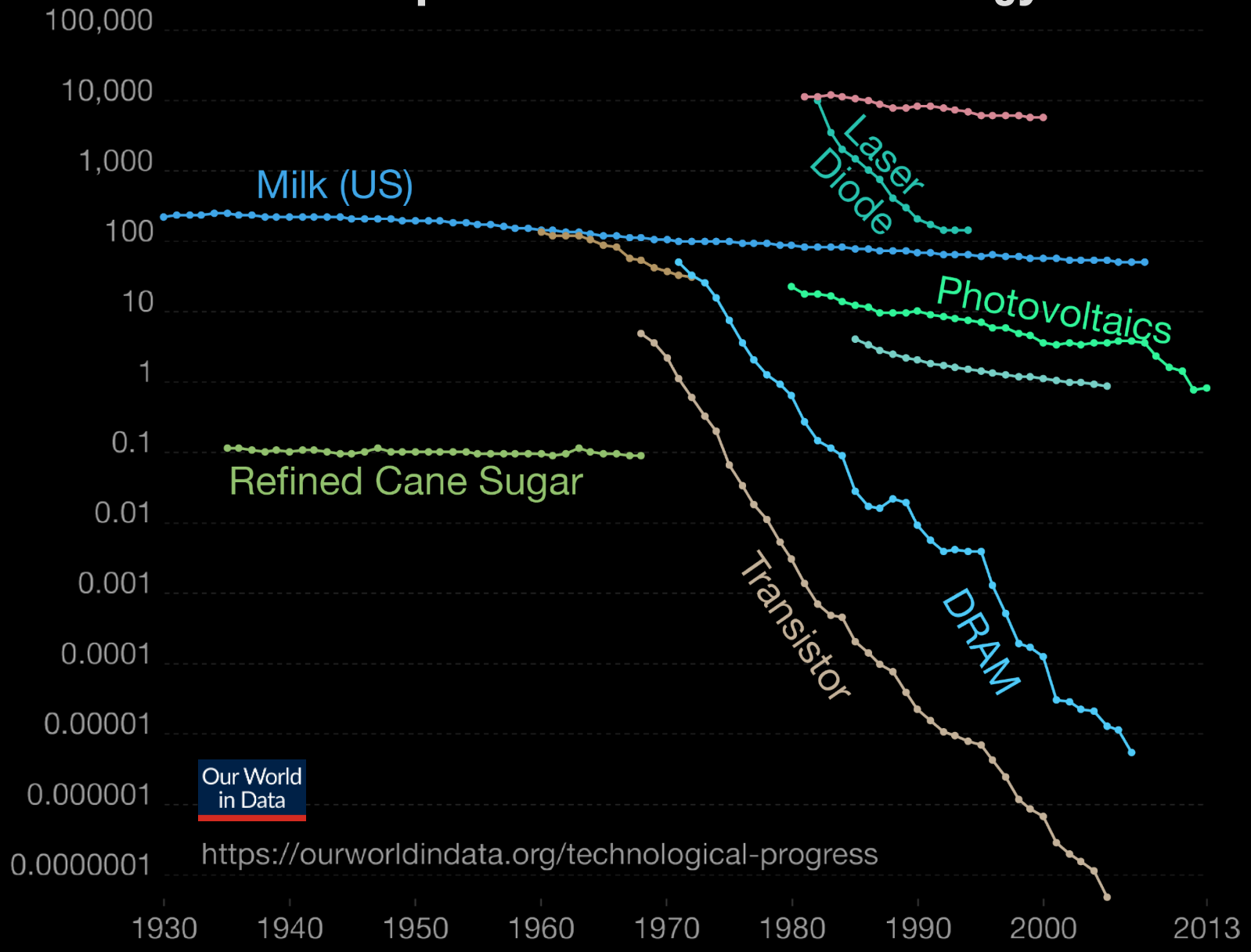
Source: J. Doyne Farmer and François Lafond (2016)

$4x10^4$ smaller

$1x10^6$ larger

Changed Human History

Transistors became 100 million times cheaper!
Almost unprecedented in technology!



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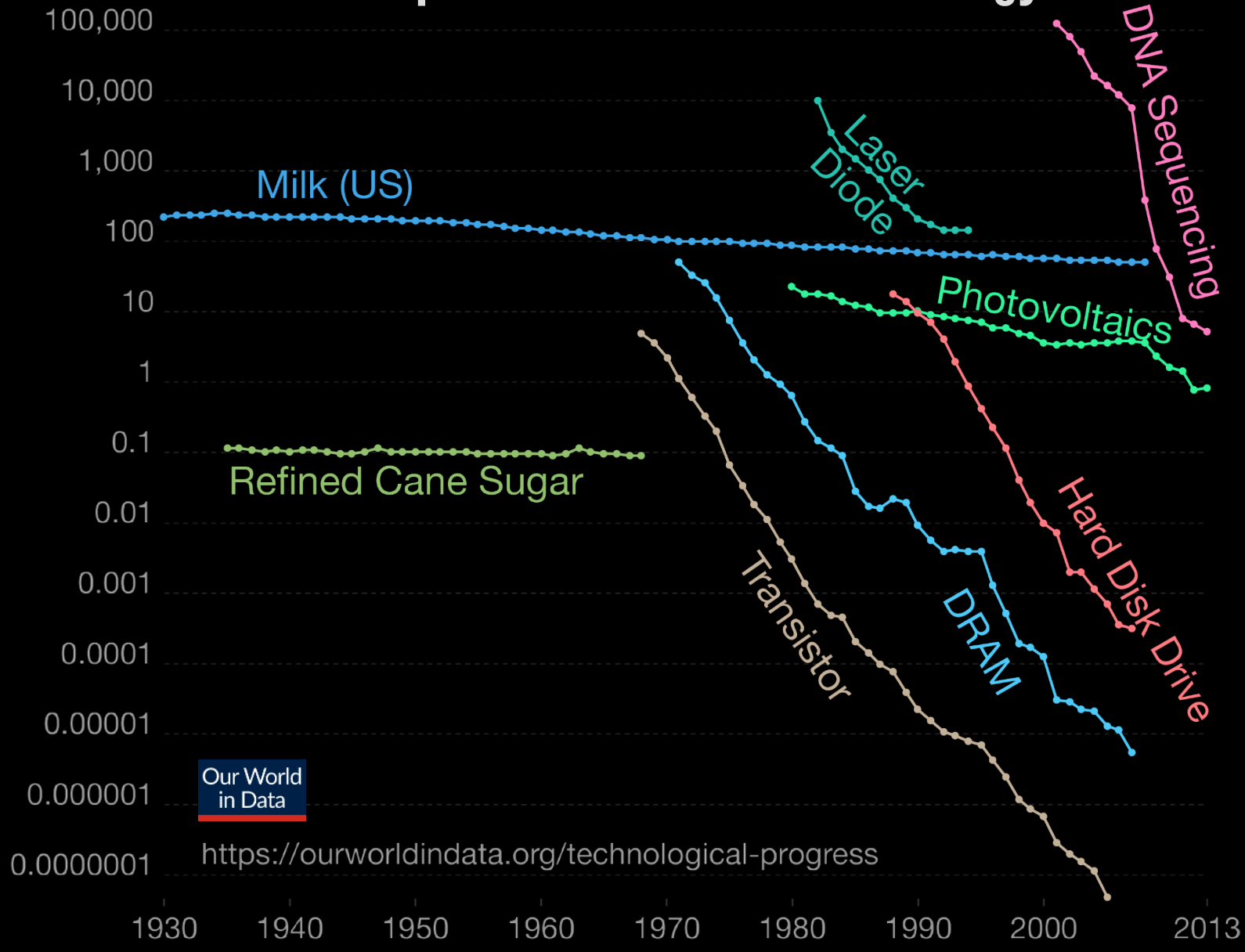

Source: J. Doyne Farmer and François Lafond (2016)

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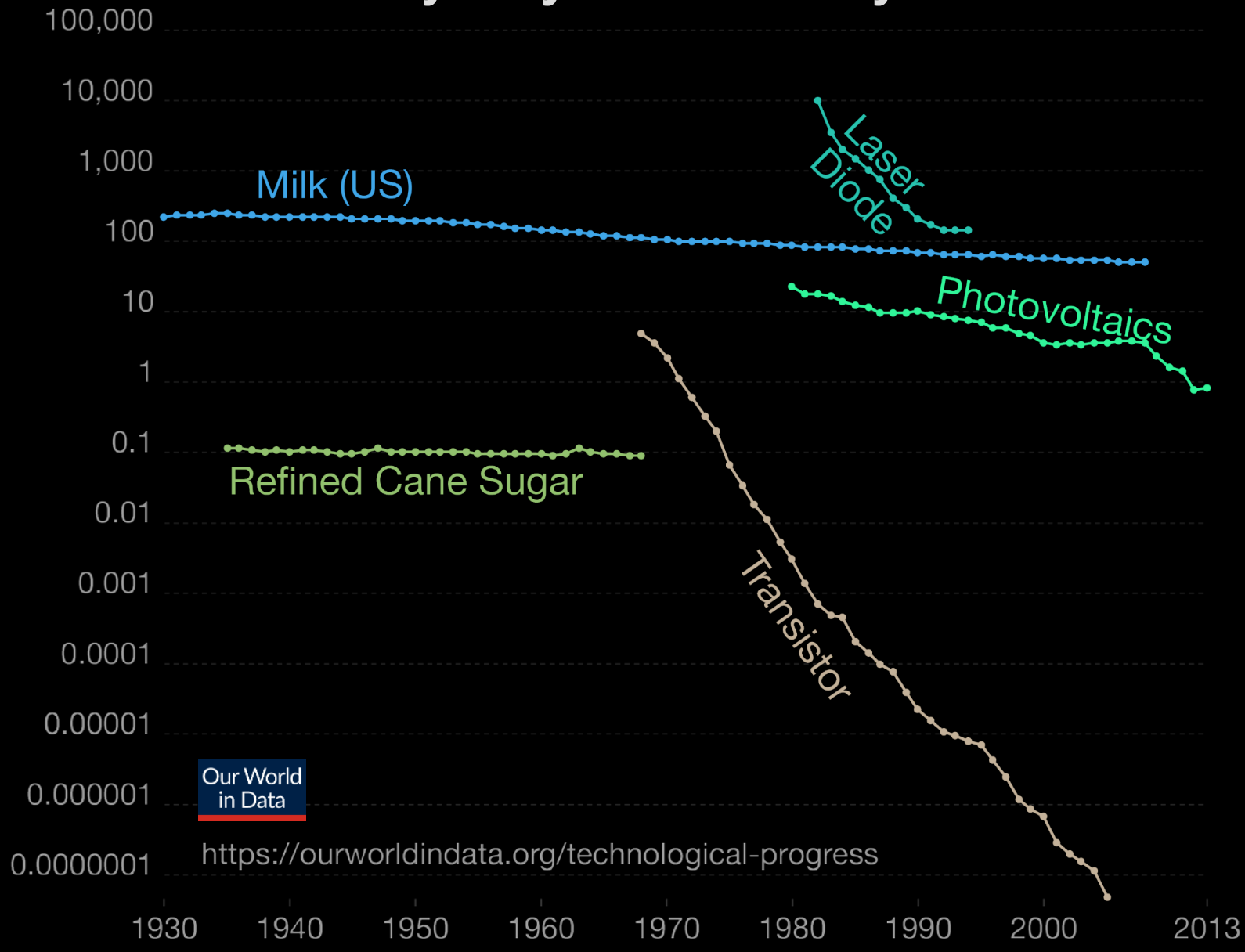
Changed Human History

Transistors became 100 million times cheaper!
That is why they CAN be everywhere!



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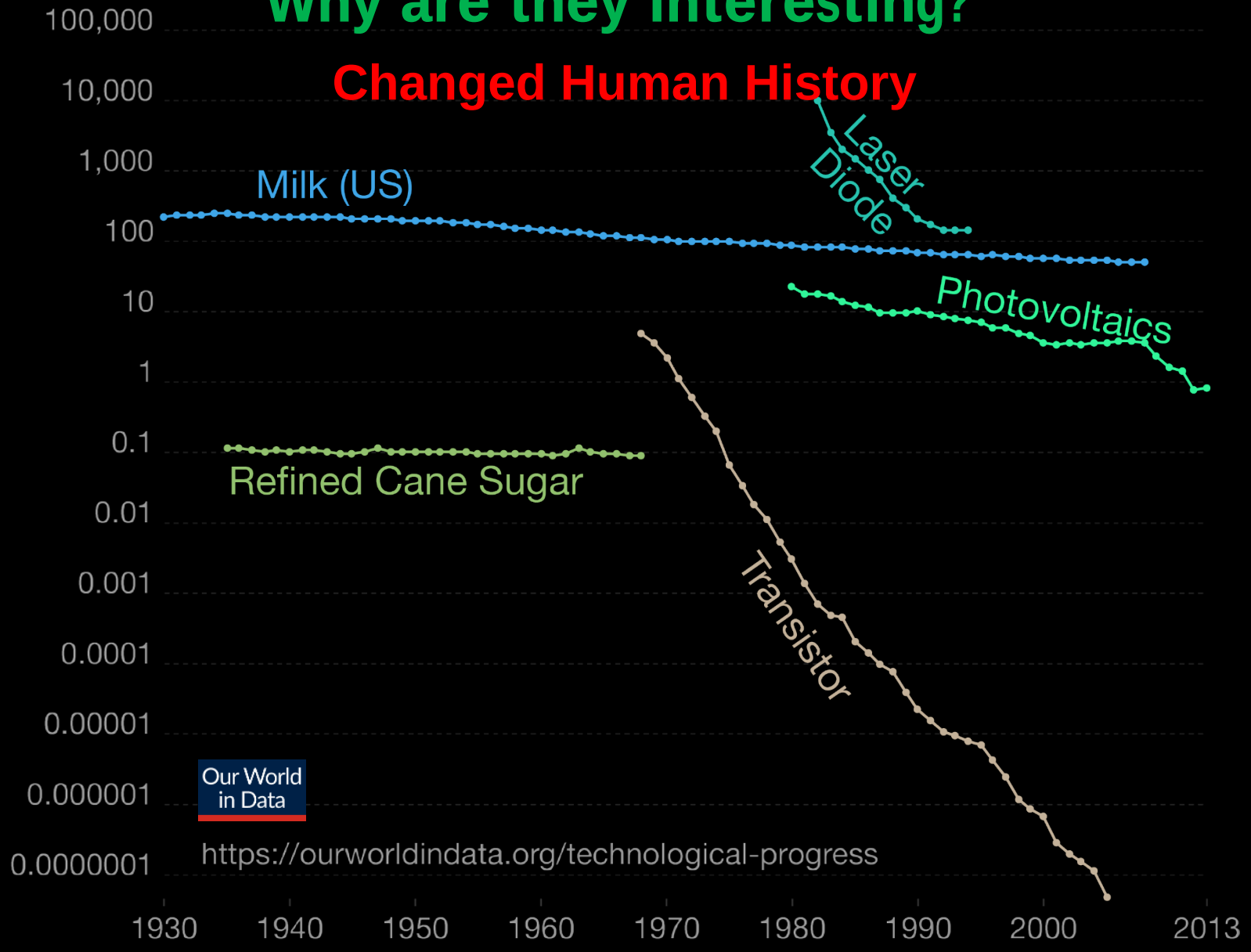
Changed Human History

Solid State Devices Section 1.1

Why are they interesting?



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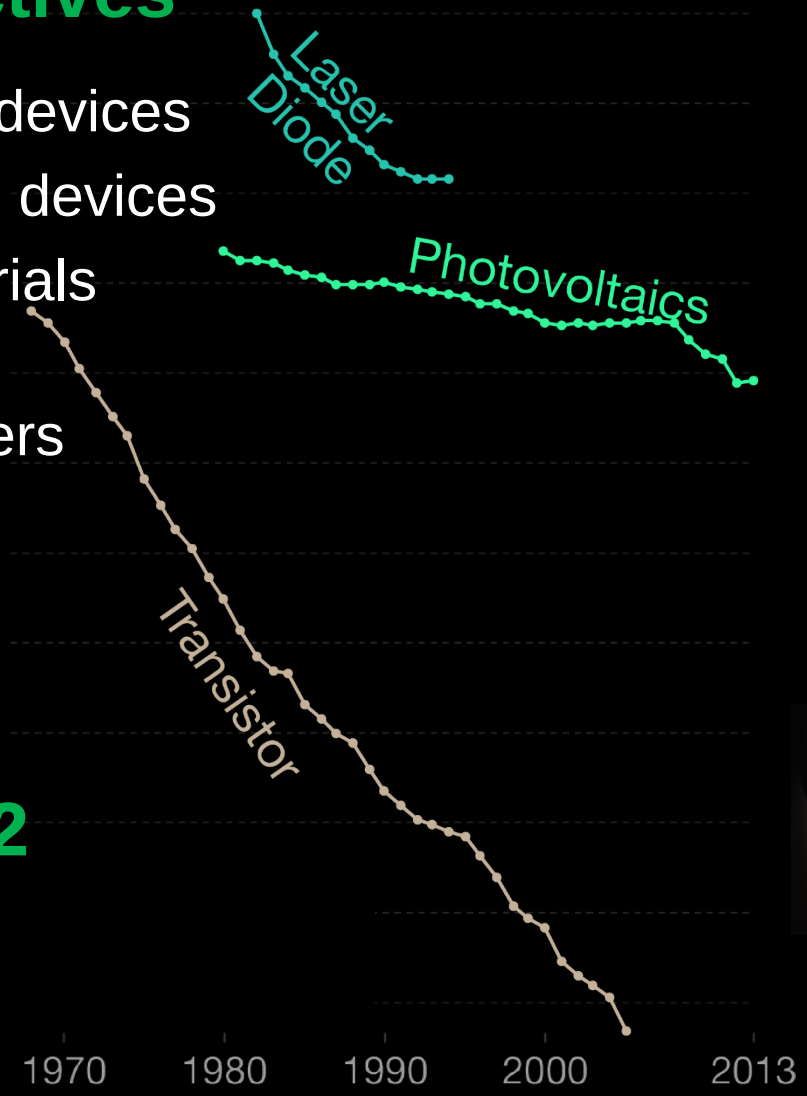
Solid State Devices Section 1.1

Why are they interesting? Changed Human History

Learning Objectives

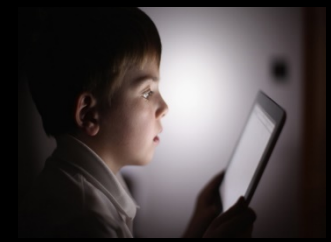
- Explain the working principles of these devices
- Explain the physical processes in these devices
- Relate the device performance to materials and design criteria
- Speak the “language” of device engineers
- Be ready to engage in device research



Solid State Devices Section 1.2

Basic Device Operations

Raising 1,000 Questions



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