New and Emerging Technologies in Electronics

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Overview

- The Next Paradigm
- Snap Shot of Emerging Technologies
- Semiconductor Technology
- Automotive Electronics
- Biomedical and Molecular Electronics
Moore’s Law – The Fifth Paradigm

CPU Transistor Counts 1971-2008 & Moore’s Law

Calculations Per Second Per $1000

What’s Next?
- 3D versus 2D device structures
- Nanotechnology
- Molecular/optical/quantum computing
- Smart/Intelligent Electronics


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Daniel F. Baldwin, Ph.D.
Ray Kurzweil: “The Law of Accelerating Returns”

- “Most long range forecasts of technical feasibility dramatically underestimate the power of future technology because they are based on an intuitive linear view rather than a historical exponential view.”

- We often overestimate what can be done in the short-term and underestimate the long-term.

- A specific paradigm (a method or approach to solving a problem, e.g., shrinking transistors on an integrated circuit as an approach to making more powerful computers) provides exponential growth until the method exhausts its potential. When this happens, a paradigm shift (i.e., a fundamental change in the approach) occurs, which enables exponential growth to continue.
Emerging Technology Around the World

- Oxford analogue event to look at bio-inspired electronics
- IMEC develops artificial skin technology
- **Liquid lenses** focus under software control
- Intel looks at shape-shifting materials based on tiny robots
- Materials bend visible and infra-red light backwards
- Surrey University unveils nanotransistor theory
- Bucky gel enables stretchable conductors
- MIT turns to photosynthesis for unlimited solar power
- Intel inside DNA sequencing
- SMIC claims 0.11-micron CMOS image sensor process
- IMEC moves 3D chips closer to commercial market
- Researchers efficiently slice germanium wafers for solar power cells
- Scottish group works on photonic microelectronics project
- IMEC raises hopes of high efficiency organic solar cells
- MIT team makes step toward human cell-sized battery
- IBM works with AMD and Freescale to build first 22nm SRAM
- Stanford, Korean nanofab centre, semi startup claim 3D IC breakthrough
- Sematech engineers advance EUV resist technology to 22nm

Source: Electronics Weekly

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Beyond Moore’s Law

- **Nanowire Computing Made Practical**
  - IBM has developed a process for making speedier and more energy-efficient chips. One of the leading candidates for a technology that could make computers smaller and more powerful is based on transistors made from **semiconducting nanowires**. Read More

- **Nanotube Ink**
  - **Printable carbon nanotube** patterns could find uses in flexible displays and RFID tags.

- **Small, Cheaper Flash Memory**
  - Freescale Semiconductor is using **nanoscale materials** to halve the size of flash memory and make it much less expensive.

- **Trying for a Terahertz Transistor**
  - A new transistor design aims to smash speed records.

- **A New Spin on Computing**
  - Researchers have found a material that could allow the use of **spintronics** to make more-powerful computers.

- **A Universal Chip for Cell Phones**
  - A single chip for wireless devices that's multifunctional, more energy efficient, and space saving is in the works.

- **Holograms Break Storage Record**
  - New technology has almost twice the storage density of a magnetic hard drive.

- **Carbon Nanotube Computers**
  - IBM researchers have made an important breakthrough: arranging nanotube transistors for complex circuits.

- **A Breakthrough in Nanotube Transistors**
  - High-current transistors made from perfectly aligned carbon nanotubes show promise for use in flexible and high-speed nanoelectronics.

- **Bringing Light to Silicon**
  - Intel has announced a new **silicon laser** that can transfer data on a beam of light—and could make **computers many times faster**.

- **A Laser Technique Could Improve Electronics**
  - This novel process might lead to purer silicon -- and faster chips.

- **How to Burn a Three Terabyte CD**
  - A new **nano-optical device** can focus laser light tighter than traditional optics, which could lead to higher-density data storage.

- **An Enhanced Hard Drive for Your Media**
  - Hardware manufacturers are staving off storage limits by making bits stand rather than recline.

- **Nanowire Transistors Faster than Silicon**
  - Advances in nanowires show they can be fast enough to use as ultrasmall transistors in cheap, high-performance electronics.
Silicon Fabrication Technology Nodes

- New technology generation every 2 years
- R&D technologies drive this pace well into the next decade

Source: Intel
Vacuum Dielectrics

- A main source of the signal lag is not so much the metal interconnects themselves but rather the insulation between the wires. So the question is, what can you put between those wires to prevent the signal from leaking?
- Vacuum is the best insulator known.
- IBM’s Air-gap technology carves nanoscale holes into the insulation between a chip’s copper wires, as seen in this electron micrograph.

Source: IEEE Spectrum
Semiconductor Nanowires

- New strategies, including the use of **novel materials** and **one-dimensional (1D) device concepts**, innovative device architectures, and smart integration schemes are being explored and are crucial to extending current capabilities the post CMOS era.
- Functional nanostructures, particularly one-dimensional semiconductor nanowires have been demonstrated.

Demonstration of first vertical surround-gate Si-nanowire transistor, see image at right. A surround-gate allows the optimal electrostatic control over the channel.

Source: IBM
Nonvolatile Molecular Memory

- Researchers have discovered a new way to switch current on and off in graphene, pointing the way to the possibility of molecule-size memory.
- Graphene is a 1-atom-thick carbon molecule in which electrons flow 100 times as fast as they do in silicon. In theory, a graphene transistor would be 100 times as fast as the same device made of silicon. One challenge, though, is that graphene is so conductive that it’s hard to stop current from flowing, and such on-off switching is necessary for any sort of transistor.
- It is believed that with graphene, a device could, in principle, be scaled down to a 1-nanometer-by-1-nanometer size.
- The switching is not fast enough to be used in a logic circuit, and researchers have not yet shown that it will work for the millions of cycles a memory device would require.
- Graphene is presently one of the most expensive materials on Earth. It is the strongest substance known to man and can be made into a conformal surface.

Source: IEEE Spectrum
Wikipedia
Memristor

- Fourth basic element in integrated circuits that could make it possible to develop computers that turn on and off like an electric light.
- Short for memory resistor
- A class of passive two-terminal circuit elements that maintain a functional relationship between the time integrals of current and voltage.
- Results in resistance varying according to the device's memristance function.
- Specifically engineered memristors provide controllable resistance useful for switching current.
- Could make it possible for memories that retain information even after the power is off, so there's no wait for the system to boot up after turning the computer on.
- May even be possible to create systems with some of the pattern-matching abilities of the human brain.

Source: HP
Examples of Electronics Technology Trends

- **Wireless and Mobility**
  - Integrated Radio in Silicon
  - Wireless Sensor Networks
  - Computing and Communication Convergence
  - Mobility Management Technologies
  - Interactive Workstations/Screens

- **Digital Home**
  - Digital Media Throughout
  - Electronic Building Technologies
  - Ultra-Wideband (UWB) Technology
  - Interactive Movies
  - Interactive Gaming

- **Security and Tracking**
  - RFID
  - Finger Print Security
  - Retinal Security
  - Travel Security

- **Enterprise**
  - Peer to Peer Computing
  - Smart Machines

- **Networking and Communications**
  - Wireless Networks
  - Broadband Wireless Access Technology (e.g. WiMAX)
  - UWB
  - Internet SCSI

- **Antennas and Radars**
  - Adaptive
  - Conformal

- **Displays**
  - Heads up displays
  - Liquid Crystal on Silicon - LCOS
  - Printed display technology
  - Printed electronics
Electronics - Communications Tablet

- Global Reach
- Internet / Internet Access
- News & Broadcast
- Personal Comm
- Multi Frequency
- Doodle Pad
- $250

Core production rate 1 million units/week, 37 variants

Source: Prismark Partners
Communication Surface

- Digital communication platform
- Touch screen interactive
- Table top work surface

Source: Microsoft
Wireless Connectivity

- RFID Tags and Smart Tags
  - Characteristics
    - Very Low Cost
    - Polymer/Paper Substrates
    - Passive Power
    - Active Devices
  - Applications
    - Library Books
    - Clothing
    - Warehousing
    - Production
    - Inventory Control
    - Security
  - Projected Volume: 1 to 10 Billion Annually
Thin Film Solar Cells

- The cells are manufactured on 0.6-by-1.2-meter sheets of glass, which are cleaned and cut on an angle to produce the strong, defect-free edges required for processing. The glass has already been coated with a transparent tin oxide that provides electrical contact to the device.

- This starting platform is radically different from that for silicon cells, which are made from far smaller monocrystalline and polycrystalline wafers.

- An elemental vapor deposition process takes place in four chambers. Glass is placed on rollers and fed into the first chamber, where it is heated to 600 °C. Then it is transferred into the second chamber, which is full of cadmium sulfide vapor, formed by heating solid CdS to 700 °C. The vapor forms a submicrometer deposit on the glass as it moves through this cloud, after which a similar process in a third chamber adds a layer of micrometers-thick CdTe in about 40 seconds. Then a gust of nitrogen gas rapidly cools the panels to 300 °C in a fourth chamber, strengthening the material so that it can withstand hail and high winds.

Source: First Solar
Organic Electronics

- Organic semiconductors are strong candidates for creating flexible, full-color displays and circuits on plastic.
- Using organic light-emitting devices (OLEDs), organic full-color displays may eventually replace liquid-crystal displays (LCDs) for use with laptop and even desktop computers. Such displays can be deposited on flexible plastic foils.

An organic passive-matrix display on a substrate of PET, a lightweight plastic, will bend around a diameter of less than a centimeter.

- Currently, efficiencies of the best doped polymer and molecular OLEDs exceed that of incandescent light bulbs. Efficiencies of 20 lumens per watt have been reported for yellow-green-emitting polymer devices, and 40 lm/W attained for phosphorescent molecular OLEDs, compared to less than 20 lm/W for a typical incandescent light bulb. It is reasonable to predict that soon, efficiencies of 80 lm/W—a value comparable to that of fluorescent room lighting—will be achieved using phosphorescent OLEDs.
- It is reasonable to assume that within 10 years, the square footage of organic circuitry might exceed that of silicon electronics.

Source: IEEE Spectrum
Organic Transistor

- A transistor that emits light and is made from organic materials could lead to cheaper digital displays and fast-switching light sources on computer chips, according to the researchers.

- The new organic light-emitting transistor (OLET) is much more efficient than previous designs. It has an external quantum efficiency of 5% (0.6% for previous designs), compared to an OLED based on the same material of 2%.

- A transistor-based light source would switch much faster than a diode, and more easily integrated onto ICs providing faster data transmission across chips than copper wire.

- The unique three-layer structure leads to higher efficiency. Current flows horizontally through the top and bottom layers—one carrying electrons and the other holes—while carriers that wander into the central layer recombine and emit photons.
Electronics companies are looking at ways to graduate from silicon electronics to printed organic electronics, with the hope of a 100X cost reduction, driven by roll-to-roll direct printing on flexible plastic substrates.
Printed Displays

Figure 1

Work-in-progress displays using imaging film from E Ink Corporation.

Source: E Ink

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3D Integration/IC Market and Roadmap

Memory
- Via: >20um by Laser
- Hole: >100
- t: <50um

NAND
- Via: 1-5um
- Hole: <100
- t: 20-50um

Logic
- t: =50um
- Via: 5-10um
- Hole: >100
- t: 200um

CMOS Image Sensor
- Via: 40um
- Hole: <100
- t: 200um

Organic Interposer

High Speed

Multi-Function

Small vias

Vias density

Thin wafer

Multi-layer

MFOC

RF

DRAM

Logic

Sensor

Analog

MPU

2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
Embedded Chip or Chips First Technology

Embedded Chips in PCB – Technology Approaches

**Intel** - Bumpless Build-Up Layer

**Casio** - Embedded WLP

**Imbera** - Integrated Module Board

**GE** – Chips First Build-Up™

**Fraunhofer IZM** - Chip in Polymer

Source: Fraunhofer IZM
IZM Fraunhofer - Chip In Polymer

Chip in Polymer – Basic Process Flow

- conventional (multi-layer) substrate
- **die bonding** of thin chips ($\leq 50 \, \mu m$) with Cu bumps (5 $\mu m$)
- embedding of chips by vacuum **lamination** of RCC™ (Resin Coated Copper)
- **laser drilling** of vias to chip and substrate
- **Cu metallization** of vias
- **structuring** of Cu layer
- optional processing of further layers
3D integration represents a system-level integration scheme wherein multiple layers of planar devices are stacked and interconnected using through-wafer vias in the Z direction.

Figure 1
Schematic diagram of three-dimensional integrated circuit (3D IC) showing two stacked device layers with their corresponding metallization levels and inter-device-layer connections (vertical interconnects).
# 3D Wafer Level Packaging Technologies

## 3-D Processes

<table>
<thead>
<tr>
<th>Process</th>
<th>RPI</th>
<th>Fraunhofer-Munich</th>
<th>ASET Japan</th>
<th>Tohoku University Japan</th>
<th>IBM</th>
<th>Infineon</th>
<th>MCNC-RDI</th>
<th>Toshiba</th>
<th>Tezzaron</th>
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<td>4</td>
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<td>Cu-Sn eutectic</td>
<td>In/Au bumps</td>
<td>Si fusion</td>
<td>Cu-Sn-Cu</td>
<td>Polymer or bumps</td>
<td>Bumps</td>
<td>Cu-Cu</td>
</tr>
</tbody>
</table>

Source: Semiconductor International
3D Vertical Integration Techniques

- Keys to achieving vertical integration of systems attributed to technology advancements
  - Advances in chemical-mechanical polishing (CMP) allowing surface planarization to a level of roughness comparable to virgin materials
  - Acceptance of copper as a primary metallization material for the CMOS process diffusing issues surrounding the introduction of a back-end-of-line (BEOL) metal into the mainstream process
  - Advances in through silicon via (TSV) technologies
  - Advances in wafer-to-wafer bonding have enabled vertical stacking of layers and device structures
    - Metallic thermal-compression bonding
    - Low temperature bonding
    - Bond alignment accuracy
3D Wafer Level Integration Strategies

- **Primary interconnection strategies**
  - Wafer-to-wafer (W2W)
  - Die-to-wafer (D2W)

- **Some believe W2W bonding is being supplanted by D2W bonding because of D2W's ability to:**
  - Assemble only KGD
  - Easier alignment tolerances
  - Ability to interconnect die of dissimilar sizes
  - Ability to interconnect die from dissimilar size wafers for “heterogeneous integration”
3D WLCSP – Wafer Level FC/SMT

- New package technology that leverages existing infrastructures for wafer level packaging technology including wafer level redistribution and wafer level ball drop and high speed flip chip assembly technology.

- Package architecture consists of a base silicon wafer having IO redistribution at the wafer level that includes flip chip interconnect pads for a mating die and solder balls for 2nd level interconnect. The die is mounted using conventional flip chip techniques and is thinned to prevent 2nd level assembly interference.
3D WLCSP – Wafer Level FC/SMT

- Leverages D2W process technology
- Leverages existing manufacturing infrastructure
- Low cost 3D wafer level integration technology
- Limited in 3D stack height
3D Wafer Level Package Assembly
3D WLCSP – 2nd Generation
Silicon Through Vias

Silicon Through-holes
(courtesy of RTI)

Fine Pitch Flip Chip

WLCSP Technology

Source: Flip Chip International
Automotive Electronics

- Sensor Rich Environment
- Electro Mechanical Replacement
- Networked Subsystems
- Telematics
- Wire Harness Elimination Auto Drive and Systems for Platooning
  - Adaptive Cruise Control
  - Radar Warning
  - Collision Avoidance
  - Electric Steering
  - Higher Voltage Power Systems
- Intelligent Transportation
  - advise or warn the driver (*collision warning*),
  - partially control the vehicle, either for steady-state *driver assistance* or as an emergency intervention to avoid a collision (*collision avoidance*), or
  - fully control the vehicle (*vehicle automation*).
Optoelectronics - Current Assembly with Fiber Management and Splicing

- Optical Component Attach
- Fiber Handling/Routing
- Fusion Splicing
- Connector Cleanliness
- Complete Analog Testing / Debug

Source: Celestica
Optoelectronics - Emerging Integration Technology

Optoelectronic Circuit Board

Opto Electronic Multichip Module (Low Cost)

Si CMOS VLSI receiver
Photodetector
Bump bond
Waveguide
Preferentially coupled beam
Graging coupler

SOP Substrate (GT SOP)

Source: Georgia Tech
Board Level Waveguides
High Speed Optical T/R Module
Optical Cross Connect Switch

- 16 Flip Chips
- Die Attach
- Wirebonding
- Multiple Materials
  - Silicon
  - PCB
  - Flex
  - Solder
  - Epoxy
  - Gold Wire
MEMS Enabled Technology

- **Sensors/Actuators**
  - YAW RATE SENSOR

- **RF Subsystems**
  - RF FRONT END MODULE
  - RF MEMS

Source: Prismark
Bioelectronics

- Bio-sensing/Drug Delivery

- 1000 resevoirs on 10 x 10mm device
- Preprogrammed drug, reagent, other chemical release
Bioelectronics - Artificial Vision

- Degenerative retinal diseases
  - Age-related Macular Degeneration
  - Retinitis Pigmentosa

- Devices electrically stimulate the healthy ganglion cells in the retina corresponding to wirelessly transmitted video data from outside the body, thus effectively bypassing the dying photoreceptor cells.
Bioelectronics

- Electronic Pills

- Designed to treat gastrointestinal disorders, goes a step further, dispensing medication at a location and rate programmed by a physician. The disposable capsule, which is about the same size as an ordinary pill, contains a tiny computer, a wireless transmitter, and a series of sensors; it passes naturally through the digestive system after being swallowed with food or water.

A. Microprocessor
B. pH Sensor
C. Temperature Sensor
D. Fluid Pump
E. Wireless Transceiver
F. Battery

Source: Technology Review
Electrotransport technology enables patient-controlled, pulsatile and macromolecule delivery through intact skin.

Systems use low-level electrical energy to transport drugs through intact skin, addressing pharmaceutical challenges such as:

- Compounds that cannot be delivered by passive transdermal systems
- Potent drugs that must be delivered in small, precisely controlled doses
- Therapy that demands pulsatile or patient-controlled delivery
- Complex delivery patterns, including ascending, descending, variable or circadian delivery
Molecular Electronics

- **Molecular Electronics has two main strands:**
  - Use of organic materials in macroscopic combinations to form electronic and optoelectronic devices (typically micrometer scales)
  - Use of functionality in individual molecules to provide molecular-scale electronic device (typically nanometer scales).

- **Potential Devices**
  - Low Cost Disposable Lab on a Chip
  - DNA Detectors
  - DNA Manipulation
  - Molecular Synthesis Platforms
  - DNA Sequencing
Walking Molecules

- This tiny machine made of just one molecule can carry other molecules on a surface. The technique can be used to move atoms or molecules close to each other, controlling when they react. The new "molecule carrier" could eventually lead to more-efficient catalysts and new methods for assembling molecular electronics.

- Anthraquinone molecules move in a straight line on a copper surface, while carbon dioxide moves randomly. But when the two molecules get close together, the anthraquinone picks up the carbon dioxide and keeps walking. The "molecule carrier" is able to carry two carbon dioxides.
Molecular Electronics - DNA Sample Analysis

- Nanogen’s technology focuses on analysis of unknown charged biological molecules which are capable of binding specifically to known capture molecules on a microchip focusing on DNA-based sample analysis. The system consists of both a disposable cartridge containing a proprietary semiconductor microchip and a fully automated instrument.

- Electronic Addressing
  - Placement of charged molecules at specific test sites
  - Leverages strong negative charge of DNA
  - Electronic manipulation
  - Solution of DNA probes is introduced and chemically bound to designed site
  - An array of specifically bound DNA probes can be assembled or addressed on the microchip.

- Disposable Cartridge
- ASIC Microchip
- Permeation Layer
- Capture Probes

Source: Nanogen
Summary

- Exciting time for electronics
- Advances in electronics technology will continue to drive the industry.
- Notable advances
  - Molecular electronics
  - Bio-electronics
  - Automotive electronics
  - Smart electronics
  - Display technology
  - Telecommunication electronics
  - Military electronics