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Semiconductor Microprocessors – Situational Analysis for India

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Abstract
Technology-dependent human evolution is an irreversible process. Information and communication technology (ICT) has encapsulated every stream of knowledge by this day, in 2021. Existence of life cannot be imagined without ICT. All spectrums of the ICT are in turn dependant on the semiconductor microprocessor chip, popularly known as microchip or simply chip. The demand of the microprocessor chips was pegged at INR 32.0 Lakh Croresgloballyand estimated at INR 5.20 Lakh Croresin India by 2015. India depends on the importfor100% of the required number of microprocessors. Indian academia has failed to recognize thecritical significance of microprocessor manufacturing knowledge. In absence of indigenous manufacturing of microchips, the country runs the risk of interruptions in the supply due to global shortage or denial of supply due to geo-political competition or conflicts. Though late, but country needs to augment its knowledge base for indigenously manufacturing the microprocessors. As chip manufacturing involves variety of academic disciplines, academia needs to introduce related syllabus in all related disciplines. It involves science and engineering in the disciplines of Physics, Chemistry, Lithography, Mining, Metallurgy, Chemical, Mechanical, Electrical, Electronics and Computing. Looking at visible and invisible risks, country is facing huge challenge before very capable students and workforce. In money terms size of challenge works out to INR 10.00 Lakh crores by 2025. By the time country learns on fast track, demand of the chips can be supplemented by reuse of discarded chips having 75% balance useful life. Wasting two third of the useful life of the costly imported chips is drain for the country, not having access to computing devices for two third of it's needy population. Case study is presented to demonstrate that demanded computing power can be met through reused microprocessors for low end of deprived users at one third of cost of ownership. Full utilization of the almost 30 years of the life span of the microprocessor could also avoid sizable amount of the pollution through e-waste. Paper presents situational overview of the microchips, it's manufacturing status, in India and ways to supplement supply of the microprocessors amidst exploding demands.
Key words:*Semiconductor, Microprocessor, Microprocessor manufacturing, Microchip, Chipset, E-waste, Re-use of microchips, Lithography, Atmnirbhar.*

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I. Introduction

India is curious case of getting fooled under full knowledge. One eyed IT jacks are pushing two eyed blinds into the deep well. Despite having dearth of knowledge and hype around competence in IT, it is still operating at 8th layer of OSI. Foundation layers of OSI, hardware as well as software are still out of reach to the ICT scientists and entrepreneurs of India. Thought of Self-reliance in microprocessor, Operating software, programming languages has yet not caught attention of researchers and policy makers. Focus of all the computing intelligence is centred at size of salary, self-reliance has been kept at bay.

People with eyes, owe moral responsibility of leading a blind to safety. Indian ICT force need to align their moral responsibility towards country. Wisdom from Sanskrit define types of blindness –

"न पश्यति जन्मान्धः कामान्धो नैव पश्यति । न पश्यति मदोन्मत्तो ह्यर्थी दोषान्न पश्यति ॥ (GP Editors, 2019)

One who is blind by birth, is ridiculed, for not being able to see the physical world. but there are bigger blinds than him/her. Blindness is worse if caused by their lust, ego or avarice, krodha (anger), moha (delusion,([illusion of)attachment), matsara (jealousy)".

The blindness caused by the burning lust, ego, and greed make us blind to what is good or bad, right or wrong. Blindness about over dependence on external microprocessors appears from the collective delusion and lust of people educated in IT in India, especially in computing.

It is half century since 1971 when first commercial microprocessor came into existence. India is still dependent on the microprocessors. Indian IT or ICT is a castlein air, addingfloors upwards. Foundations are all borrowed and resting on risky rugs. These rugs can be pulled from beneath, instantly, to bring down whole castle beyond rescue. Fascination and Propagation of IoT will gradually eat away self-reliance up to the risk of loosing sovereignty of the country. Anyone in the control of microprocessor and OS will have control on everything, public policy, governance, research, weaponry, war strategy, audit, financial institution to name few. Do we need invasion of any other kind for loosing independence once again ?

Advanced computer chips drive economic and scientific advancement as well as military capabilities. Complex supply chains produce these chips, and the global distribution of these chains and associated capabilities across few nations have major implications for future technological competition and international security. Current world order is struggling around microprocessor manufacturing capabilities. Taiwan a considerable player in the field, has already become bone of contention between USA and China, the main competitors in the field of electrical & electronic components (EEC) , microprocessors are core of the all EEC.

India, a country of 130 Crores people does not have any share in microprocessor manufacturing. While it consumes 20 % of all microprocessors manufactured in the world. India is fully dependent on the imports of microprocessors separately or fitted in the ICT devices / equipment. Size of imports is third after petroleum and edible oils.

In nearly half a trillion dollar global supply chain of semiconductor chips, Indian share is hopelessly zero. USA and allied countries have more than 93% dominating share in the supply chain while China is fast emerging competitor with 6% share. Taiwan and South Korea are contributing sizably for market share of USA(Saif M. Khan, 2021).

The United States and its allies are global semiconductor supply chain leaders, while China has begun to challenge. India has yet not set it's foot in the global market. The U.S. semiconductor industry contributes 47 % of the total value of the global semiconductor supply chain. allied nations , Japan, European union, Taiwan, and South Koreacollectively contribute 46% together[https://www.statista.com/statistics/510374/worldwide-semiconductor-market-share-by-country/]. These countries and regions enjoy a competitive advantage in virtually every supply chain segment. While contributing only 6 %, China is quickly developing capabilities across many segments and could attempt to reconfigure supply chains in it's favour, impacting national and international security.

Present political dispensation has realized the criticality of the indigenization of the chip and given a kick start for the in-country design and production of chips in 2017. Government has come up with immensely innovative ideas for achieving the results very fast for making-up for ignorance by previous regimes. In an attempt to make a mark in the highly competitive segment of microprocessor manufacturing, engineers from the Indian Institute of Technology Bombay (IIT Bombay) have developed a new microprocessor called 'AJIT'the first ever microprocessor to be conceptualised, designed, developed and manufactured by India in 2017. Efforts have been boosted by "Swadeshi Microprocessor Challenge 2020" as a step towards the Prime Minister's ambition of "Atmanirbhar Bharat". Other indigenous microprocessors 'SHAKTI' , 'Moushik' from IIT Madras, 'AGUMBE' from a company promoted by Dr Sridhar Vembu and 'VEGA' from C-DAC came up in very short period from 2018 to 2020 ((MeitY), 2020).

After developing microprocessor chip design and production capabilities exhibited in the form of AJIT, Shakti, VEGA, AGUMBE and MOUSHIK, Indian chip industry has come out of cradle and eager to walk in highly competitive and fast changing busy lane.

As chips are items of scientific and technological elite, they are doing terrific job under strong political will for ''*atmnirbhar*" Bharat. But consumption side of the chip needs use based rationalization and utilization of the value to it's fullest extent. Today, chips relate to every person of the society, from military strategists to delivery boy for the grocery. In a cold war scenario between democracy and other forms of governance, stakes are very high on the technology. Today, the term technology is solely dependent on chip in our contemporary times. Information asymmetry on microchip can help an enemy winning war and enslaving country , remotely. Citizen of the country needs to be aware of such risks related to technology, very fast. Country needs to fast gear up developing critical building blocks of ICT the chip, the operating software and programming language. There is strong need for the trade-off between adoption of automation and capabilities in microchip development. Pace of adoption of automation should match the capabilities in microprocessor, operating software (OS) and programming languages. **Country is already rich in coding talent, out of proportion emphasis on coding hardly adds to the technological strength of the country.**

As rise in demand of microprocessors is unavoidable, India needs to learn about microprocessors very fast. Augmentation of supply can come from imports, manufacturing inhouse and smart use of balance useful life of already available with us. Balance useful life of microprocessors is estimated at 75% or 15 years. Currently, microprocessors are discarded within 05 years, as norm. Most of them are discarded with ICT devices like computer and phone leaving lots of value, unused.

This paper is motivated by the loss of value in discarded microprocessors and lack of capabilities of the country in microprocessor manufacturing. Fast replacement of ICT devices for social status not only drains

the value but contributes to the dependence. Discarded systems have lot of value available for use by needy users. Paper is trying to answer the research question “Can developing country like India with 28% population below poverty line , afford to drain unused value in microprocessors ? ”. Can education system not be aligned toward development of the eco system for self-reliance in core components of ICT ?
Paper presents overview of the microprocessor chips, manufacturing of the chips, status in India, supply and demand, useful life of the chips, strategic thinking about minimization of import and e-waste.

Terms and specifications:
Application-specific integrated circuits (ASICs) are logic chips which are specially designed for certain applications.
Assembly and packagingtakes a wafer with completed, unseparated chips and converts them into separate, packaged chips.
Central processing units (CPUs)are the general-purpose logic chips designed to perform variety of calculations. These same chips can be used by different applications.
Chips, are integrated circuits, each include a set of electrical circuits made of small devices called transistors in a flat surface made of a semiconductive material such as silicon. Logic chips perform calculations on digital data (zeroes and ones) to produce outputs. Memory chips store the
digital data with which logic chips perform calculations.
Core intellectual property (IP) consists of reusable modular portions of chip designs which are incorporated into complete chip designs.
Crystal growing furnaces and machining tools are used to produce wafers, a base plate for the chip.
Chemical mechanical planarization (CMP) flattens wafer surfaces after various fabrication steps like etching and cleaning.
Cleaning removes materials from a wafer, such as materials left after etching off of a wafer.
Deposition adds thin films of materials on a wafer to make them parts of chips. Techniques include chemical vapor deposition, physical vapor deposition, electrochemical coating, spin-coating, rapid thermal processing, and tube based diffusion and deposition processes.
Design determines the layout of transistors and wiring on a chip to be manufactured.
Discrete semiconductors each include only a single electrical device, such as a transistor, unlike a chip, which includes many interconnected devices forming circuits.
Dynamic random-access memory (DRAM) is a memory chip that stores data while a computer operates, but loses it when the computer powers is put off.
Electronic design automation (EDA) software is used for designing microprocessor chips.
Electronic gates are materials used in semiconductor fabrication.
Etching tools are used for creating permanent patterns in chips. Photolithography removes portions of a photoresist deposited on a wafer in a precise pattern then etching tools etch that pattern into a permanent substrate below. Dry and wet etching respectively use gas and liquid for etching.
Fabless firms do not fabricate the chips, they design and sell chips, but buy chip manufacturing services from foundries and assembly, test, and packaging services from outsourced semiconductor firms specialised in various sub processes of the chip fabrication.
Fabrication turns designs into chips, using various semiconductor manufacturing equipment and fab materials.
Field-programmable gate arrays (FPGAs) are logic chips those can be reprogrammed after deployment to suit specific calculations.
Foundries are semiconductor manufacturing (casting) factories that manufacture chips for third-party customers.
Graphics processing units (GPUs) are specialized logic chips used most commonly for graphics processing and developing artificial intelligence algorithms.
Lithography an old technique used for printing of books. Same techniques, in modified form is used to draw patterns in chemicals (such as photoresists) deposited on a wafer in a pattern. Lithography has become fundamental process for chip manufacturing. There are variations in the technique known as photolithography, electron beam lithography, laser lithography, and ion-beam lithography.
Integrated device manufacturers (IDMs) are firms those perform all steps of production: design, fabrication, assembly, testing & packaging.
Ion implanters embed impurities (called dopants) into parts of wafers to modify their properties.
NAND flash is a memory chip that stores memory permanently, even when power is turned off.
Outsourced semiconductor assembly and test (OSAT) firms perform assembly, testing, and packaging sub processes for third-party customers.
Packaging bonds a fabricated chip to an encasing package.

Photomasks are transparent plates containing a circuit pattern. Photolithography tools pass light through these plates to transfer the pattern to the chip.
Photoresists are chemicals deposited on a wafer those selectively dissolve to form the circuit pattern when exposed to patterned light that passes through a photomask, light generated by a photolithography tool.
Process control tools monitor wafers, photomasks, and the overall chip manufacturing process for minimizing errors. These tools include tools to inspect wafers, photomasks, wafer level packaging process steps.
Resist processing tools (also called "tracks") coat and process photoresists on wafers.
Semiconductors are products produced by the semiconductor industry. These products include chips, discrete, optoelectronics, and sensors. The term semiconductor is also separately used to refer to materials with electrical properties in between conductors and insulators.
Semiconductor manufacturing equipment includes tools used to fabricate, assemble, test, and package chips.
Testing ensures fabricated chips operate as planned.
Wafers are thin, disc-shaped materials in which chips are fabricated.
Wafer bonders and aligners join silicon wafers, often after chips are fabricated in the wafers.
Wafer and photomask handlers store and transport wafers and photomasks in a fab.
Wafer marking systems mark wafers or chips manufactured in wafers with identifiers using a laser beams.
Wet chemicals are materials used in semiconductor fabrication.

From Silicon Wafers to Microprocessor chip:
Silicon wafers are basic unit for manufacturing microprocessor chips. Wafers are made in typical sized of 150, 200, 300 mm in diameter. One wafer can yield 100 to 1000 pieces , known as die to make microchip. One wafer of 200 mm diameter weighs 40 grams. Price of wafer ranges in INR 2000 or more. Man in figure 01 is holding a silicon wafer. One wafer divided into 263 section as shown in figure -02 , each section is called die and converted into microprocessor chip shown in figure – 03.

Figure 1: Relative size of silicon wafer.

No of microchips per wafer can go upto 263 or more:

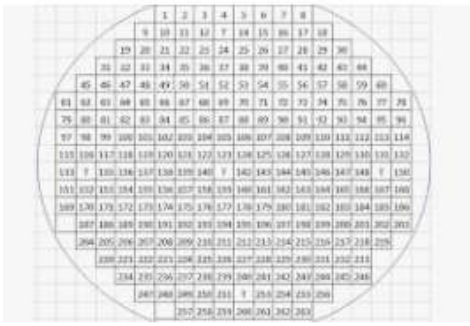

Figure 2: Chips in Silicon wafer

Finished microprocessor chip :

Figure 3: Finished microprocessor chip

Specifications of Microprocessor:
Subject matter of microprocessor specification is wide and complex. It is as complex as specifications of a software application. There are almost as many chips as software applications. Following table No.-01 has grouped the specification parameters and their descriptions under various class of parameters like design, performance, input/ output (I/O) interphases and packaging etc. Compilation is a basic attempt to sensitize about jargons of the trade and complexity involved.

Design specifications:

Architecture:		
	RISC	Microprocessors that use a reduced instruction set computer (RISC) design process a few simple instructions rather than many complex ones in order to speed operations.
	CISC	Microprocessors that use a complex instruction set computer (CISC) design provide variable length instructions, multiple addressing formats, and contain only a small number of general-purpose registers.
	Other	Other unlisted architectures.
Data Bus	Data buses are a bidirectional set of conductive paths. Data or instruction codes are transferred into the digital signal processor (DSP).	
	8-Bit	Microprocessors have an 8-bit data bus.
	16-Bit	Microprocessors have a 16-bit data bus.
	24-Bit	Microprocessors have a 24-bit data bus.
	32-Bit	Microprocessors have a 32-bit data bus.
	64-Bit	Microprocessors have a 64-bit data bus.
	128-Bit	Microprocessors have a 128-bit data bus.
	256-Bit	Microprocessors have a 256-bit data bus.
	Other	Any other unlisted data bus.
Microprocessor Family:	The processor family of the microcontroller.	
	Intel® 8051	Intel provides Intel® 8051 microprocessors.
	Intel® x86	Intel provides Intel® x86 microprocessors.
	AMD	Advanced Micro Devices (AMD) provides microprocessors.
	Motorola 68K	Motorola microprocessors are designed for use with 68K code.
	PowerPC®	Motorola provides Motorola PowerPC® microprocessors.
	ZiLOG® Z80	ZiLOG® produces 8-bit Z80 microprocessors with dual register banks for fast context switching and interrupt handling.
	ARM	Advance Risk Machine provides 16/32-bit RISC microprocessors.
	Geode(TM)	National Semiconductor developed the Geode(TM) family of microprocessors.
	MIPS Technologies	Microprocessors without Interlocked Pipelined Stages Technologies provides microprocessors.
	SPARC®	Sun Microsystems, Inc. provides microprocessors for the SPARC® platform.
	PIC®	Peripheral interface controller (PIC®), a versatile microcontroller.
	Via Technologies	Via Technologies provides microprocessors.
	Other	Other unlisted, specialized, or proprietary microprocessor families.
Supply Voltage:		
	-5 V to **5V**	Microprocessors operate at -5 to 5V volts.

Performance specifications:

Clock Speed	Clock speed, the frequency that determines how fast devices connected to the system bus operate, is generally expressed in megahertz (MHz).
RAM	Random access memory (RAM) is generally expressed in kilobytes (KB) or megabytes (GB).
Power Dissipation	Power dissipation, the device's total power consumption, is generally expressed in watts (W) or milliwatts.

Operating Temperature	This is the range of operating temperatures. 33 deg C to 70 deg C is considered safe range.

I/O Ports and Interfaces specifications:

I/O Ports	The number of I/O ports is equal to the number of input, output, and general-purpose ports, or lines, combined.
Number of UARTs	Universal asynchronous receiver/transmitter (UART) is a circuit that accepts parallel data information and converts it into an asynchronous serial data stream.
DMA Channels	Direct memory access (DMA) is a method of transferring data directly between two peripherals with minimal processor intervention. Usually, these two peripherals are memory and an I/O device.
Interface / Port Support	Communication controllers manage data input and output to a host computer or computer network. The units may be complex front-end mainframe interfaces or simpler devices such as multiplexers, bridges, and routers. The devices convert parallel computer data to serial data for transmission over communication lines and perform all the necessary control functions, error checking, and synchronization.
TCP/IP	Microprocessors have available ports for transport control protocol/internet protocol (TCP/IP) communication.
SPI	Serial peripheral interface (SPI) is a four-wire, full duplex, synchronous serial data link. SPI was originally developed by Motorola to provide a glue less microcontroller interface to industry-standard serial devices, such as electrically erasable programmable read-only memory (EEPROM), and other serial devices.
I^2C	The Inter-IC (I^2C) bus is a two-wire serial bus designed by Phillips that provides a communications link between integrated circuits. I^2Cs are used to control and monitor applications in communications, computer, and industrial settings. Physically, the bus consists of two active wires and a ground connection. The active wires, the serial data line (SDA) and the serial clock line (SCL), are both bidirectional. Each component that is connected to the bus has a unique address and can, depending on its functionality, receive and/or transmit information.
IrDA	Infrared data association (IrDA) ports transfer data from one device to another with infrared light waves instead of cables.
SDLC/HDLC	Designed by IBM in 1975, synchronous data link control (SDLC) is the oldest two-layer protocol for carrying system network architecture (SNA) traffic. In 1979, ISO used SDCL to create high-level data link control (HDLC).
SMBus	Microprocessors use system management bus (SMBus) ports.
CAN	Microprocessors use control area network (CAN) bus ports.
USB	Microprocessors use universal serial bus (USB) ports.
JTAG Interface	The joint test action group (JTAG) created the JTAG interface to allow access to the inner workings of an IC for testing, controlling, and programming purposes.
PWM Interface	Microprocessors use pulse width modulation (PWM) interfaces.
Other	Other unlisted communication ports or interfaces.

Packaging Information

Package Type:	Description
BGA	Ball grid array (BGA) is a type of memory chip with soldered balls on the underside for mounting. Use of BGA allows die package size to be reduced because there is more surface area for attachment. Smaller packaging allows more components to be mounted on a module, making greater densities available. The smaller package also improves heat dissipation for better performance.
PBGA	Plastic-ball grid array (PBGA).
TBGA	Tape-ball grid array (TBGA).
FLGA	Fine-pitch land grid array (FLGA).
QFP	Quad flat packages (QFP) are etched or stamped with fine lead frames. This design enables QFPs to contain more leads and features in a smaller profile (the lead width can be as small as 0.16 mm while the lead pitch is 0.4 mm). The thinner and flexible leads in gull-wing shape also provide better 2nd-level reliability (package to PCB). Quad packages have been used for years to meet increasing challenges of advancing processors/controllers, ASICs, DSPs, gate arrays, logic, memory ICs, PC chipset, video-DAC, multi-media and other related applications. QFPs are widely used in consumer and industrial products, automotive technology, PCs and other related products.
LFQP	Low-profile quad flat package (LQFP).
TQFP	Thin quad flat package (TQFP).
SOP	Small outline package (SOP).
SOIC	Small outline IC (SOIC).
TSOP Type I	Thin small outline package (TSOP) is a type of DRAM package that uses gull wing shaped leads on both sides. TSOP DRAM mounts directly on the surface of the printed circuit board. The advantage of the TSOP package is that it is one-third the thickness of an SOJ package. TSOP components are commonly used in small outline DIMM and credit card memory applications. Thin small outline package may be Type I or Type II.
TSOP Type II	Thin small outline package (TSOP) is a type of DRAM package that uses gull wing shaped leads on both sides. TSOP DRAM mounts directly on the surface of the printed circuit board. The advantage of the TSOP package is that it is one-third the thickness of an SOJ package. TSOP components are commonly used in small outline DIMM and credit card memory applications. Thin small outline package may be Type I or Type II.
SSOP	Shrink small outline package (SSOP).
TSSOP	Thin shrink small outline L-leaded package (TSSOP).
TVSOP	Thin very small outline package (TVSOP).
SOJ	Small outline J-lead (SOJ) is a common form of surface-mount DRAM packaging. It is a rectangular package with J-shaped leads on the two long sides of the device.
HSOF	Small outline flat-leaded package with heat sink (HSOF).
PLCC	Plastic leaded chip carrier (PLCC).
LCCC	Leadless ceramic chip carrier (LCCC).

DIP	Dual In-line package (DIP) is a type of DRAM component packaging. DIPs can be installed either in sockets or permanently soldered into holes extending into the surface of the printed circuit board. Plastic dual-in-line package (PDIP) is widely used for low cost, hand-insertion applications including consumer products, automotive devices, logic, memory ICs, micro-controllers, logic and power ICs, video controllers commercial electronics and telecommunications. Ceramic dual-In-line package (CDIP) consists of two pieces of dry pressed ceramic surrounding a "DIP formed" lead frame. The ceramic / LF / ceramic system is held together hermetically by frit glass reflowed at temperatures between 400° - 460° centigrade.
SIP	Single inline package (SIP).
SDIP	Shrink dual inline package (SDIP).
SZIP	Shrink zigzag inline package (SZIP).
Other	Other unlisted, specialized, or proprietary packages.
Pin Count	The pin count is the number of pins in the microprocessor.

Features

PLL / DLL?	Integrated phase locked loops (PLLs) and delay locked loops (DLLs) with clock frequency synthesis capabilities allow designers to generate high-speed internal clocks for sampling data in microprocessor applications. PLLs and DLLs give designers greater control over the clock frequencies used in integrated designs. This is vital for system integration because different parts of a system operate at different clock frequencies.
Search Logic:	"Required" and "Must Not Have" criteria limit returned matches as specified. Products with optional attributes will be returned for either choice.
Watchdog Timer?	Watchdog timers are simple countdown timers that are used to reset microprocessors after specific intervals of time.
On-Chip Oscillator	On-chip oscillators are embedded.
Real Time Clock (RTC)	Real time clocks (RTCs) are embedded.
Supervisory Functions	Microprocessors have programmable supervisory functions.
Programmable Alarms	Microprocessors have programmable alarms.

Table 1: Specifications of Microprocessor

Development Journey of the Microprocessors:

Baron Jons Jackob Berzelius discovered silicon (Si), in 1823 which is the basic component of processors. Nikola Tesla patented electrical logic circuits called "gates" or "switches" in 1903. John Bardeen, Walter Brattain, and William Shockley patented the first transistor in 1948. Later first working integrated circuit was developed by Robert Noyce of Fairchild Semiconductor and Jack Kilby of Texas Instruments. The first IC was demonstrated on September 12, 1958. Geoffrey Dummer is credited as being the first person to conceptualize and build a prototype of the integrated circuit.

IBM developed the first automatic mass-production facility for transistors in New York in 1960. On April 19, 1965, Gordon Moore made an observation about integrated circuits that became known as Moore's Law. Following commercialization of the microprocessors with IC , major firms Intel, Texas instrumentals and AMD of USA began developing new versions of the microprocessors almost each year. Major commercial versions of the microprocessors are compiled in the Table No. 02.

Development Journey of Microprocessors

Year	Chipset	Clock Speed	UOM	Year	Chipset	Clock Speed	UOM
1958	First int. circuit			2000	AMD Athlon	800.00	MHz
1971	Intel 4004	750.00	KHz	2000	Intel Celeron 533	533.00	MHz
1972	Intel 8008	800.00	KHz	2000	AMD Duron	600.00	MHz
1974	Intel 8080	3.13	MHz	2001	Intel Celeron II	800.00	MHz
1976	Intel 8085	3.00	MHz	2001	Intel Pentium 4	1.30	GHz
1978	Intel 8086	5.00	MHz	2002	Intel Celeron III	1.30	GHz
1979	Intel 8088	5.00	MHz	2003	Intel Pentium M	1.30	GHz
1979	Motorola 68000	7.67	MHz	2004	AMD Sempron	1.50	GHz
1982	Intel 80286	5.00	MHz	2006	Intel Core 2 Duo	1.86	GHz
1985	Intel 80386	12.00	MHz	2007	Intel Core 2 Quad	2.67	GHz
1985	ARM1	6.00	MHz	2007	AMD Athlon X2	2.60	GHz
1988	Intel 80386SX	25.00	MHz	2008	Intel rCore 2 D E7200	2.53	GHz
1989	Cyrix FasMath	16.00	MHz	2009	AMD Phenom II X4	3.70	GHz
1991	AMD AM386	40.00	MHz	2009	Intel Core i5	2.67	GHz
1991	Intel 486SX	25.00	MHz	2010	Intel Core i7	3.20	GHz
1992	Intel 486DX2	33.00	MHz	2013	AMD Athlon II X2	3.60	GHz
1993	Intel Pentium	60.00	MHz	2017	AMD Ryzen 7	3.60	GHz
1995	Intel Pentium Pro	166.00	MHz	2018	Intel Core i9 mobile	2.90	GHz
1996	AMD K5	133.00	MHz	2020	Intel Comet Lake-S	5.30	GHz
1997	AMD K6	300.00	MHz	2020	AMD Ryzen 5000	4.90	GHz
1997	Intel Pentium II	450.00	MHz	2021	ARM Cortex-X2	3.90	GHz
1998	AMD K6-2	550.00	MHz				
1998	I.Pentium II Xeon 400	400.00	MHz				
1999	Intel Celeron	400.00	MHz				
1999	AMD K6-III	400.00	MHz				
1999	Intel Pentium III	500.00	MHz				
1999	AMD Athlon	500.00	MHz				
1999	The Intel Pentium III	600.00	MHz				

Table 2: Development Journey of Microprocessors

Development of the microprocessors continuously strived on three main characteristics processing speed , size of the chip and spacing between circuitry inside the chip. Processing speed of the chip increased from 751 MHz in 1971 to 8.80 GHz in 2012 (Perry, 2012). Size reduction of the microprocessor began from Intel 80486DX2 microprocessor with actual size of 12×6.75 mm to ARM-based chip, the Kinetis KL02, measuring 1.9mm by 2.2mm(Victor, 2013).

Microprocessor is made with billions of compacted in a single chip. The shorter the distance between the transistor in nanometre (Nm) in the processor, the more the number of transistors can occupy in a given distance. So, distance travel by electrons for doing useful work is reduced. This ultimately results in faster computing power, less energy consumption and less heat to dissipate, less thermal output around the board, size of the die will be smaller, which ultimately reduces costs and increase the density of transistor on the same size, which means more cores per chip. Intel currently uses 14nm or 10nm. There are reports of chips being manufactured with 07 Nm spacing. Spacing between circuitry inside is fast reaching to its lowest possible limit to 5 Nm.

Processing speed of the microprocessor increased 400% in past 20 years. Approximately 20% each year. Demand of microprocessors fuelled by the self-driven competition among researchers in the field. Developments were so fast that Gordan Moor’s observation first became law and later it became challenge and goal for the researchers in the field.

Moor's law states that numbers of the transiters in a circuit double in two years. Moor's law has been taken as mission statement by the computing industry. Rapid improvisation in microprocessors pulled improvisations of all other components like operating software (OS) of computing and digitization to match the power of the processor. Speed of the release of the new versions or shelf life of the versions, of the Window OS is compiled in Table – 03.

Shelf Life of OS MS Windows versions

Widows version	**Support From**	**Support To**	**Shelf Life of OS (Years)**
Windows 1.01	20-11-1985	31-12-2001	16.00
Windows 1.02	14-05-1986	31-12-2001	15.00
Windows 1.03	21-08-1986	31-12-2001	15.00
Windows 1.04	10-04-1987	31-12-2001	14.00
Windows 2.01	09-12-1987	31-12-2001	14.00
Windows 2.03	09-12-1987	31-12-2001	14.00
Windows 2.1	27-05-1988	31-12-2001	13.00
Windows 2.11	13-03-1989	31-12-2001	12.00
Windows 3.0	22-05-1990	31-12-2001	11.00
Windows 3.1	06-04-1992	31-12-2001	9.00
Windows NT 3.1	27-07-1993	31-12-2000	7.00
Windows 3.11	08-11-1993	31-12-2001	8.00
Windows 3.2	22-11-1993	31-12-2001	8.00
Windows NT 3.5	21-09-1994	31-12-2001	7.00
Windows NT 3.51	30-05-1995	31-12-2001	6.00
Windows 95	24-08-1995	31-12-2001	6.00
Windows NT 4.0	24-08-1996	30-06-2004	7.00
Windows 98	25-06-1998	11-07-2006	8.00
Windows 98 II Ed	05-05-1999	11-07-2006	7.00
Windows 2000	17-02-2000	13-07-2010	10.00
Windows Me	14-09-2000	11-07-2006	5.00
Windows XP	25-10-2001	08-04-2014	12.00
Windows Vista	30-01-2007	11-04-2017	10.00
Windows 7	22-10-2009	14-01-2020	10.00
Windows 8	26-10-2012	12-01-2016	3.00
Windows 8.1	26-10-2012	12-01-2016	3.00
Windows 10	26-10-2012	NA	
Windows 11 (Exp)	05-10-2022	NA	

Table 3: Shelf Life of OS MS Windows

Shelf life of the new versions of the OS came down from 15 years to 03 years following pull of the demand by new features in computing and push from semiconductor developers to consume and fund the new versions of the microprocessors. New and improved versions of the chip released almost every year. It is like , end users switching the food bytes, half chewed to the better available byte. Lots of balance useful life wasted in the quest of onboarding new.

Technology growth has been driven by Moor's law like a mad race. Consideration of wastages did not strike the minds of the players in the microprocessor technology. As assimilation of any technology takes time, end users are in the state of run to catch up the speed of developments before getting any return from her previous investment. End users got dragged into the mad race of the technology they never demanded.

It would be difficult to exactly pin point the driver for the growth of the microprocessor industry. Moor's law, Internet, weaponization race and literacy rates seemingly pulled the growth of the industry. Resulting electronic garbage size too grow many fold. India generated 3.23 Million Tonne of e-waste in 2018-19 and at world level it was 53.6 Million Tons in 2019 (KANCHARLA, 2020).

Despite the huge aggregate demand for microprocessors generated through push and pull, manufacturing of the chips remained with Intel, controlling the market share above 20% upwards. Other significant players are Advanced Micro Devices (AMD), Toshiba Electronic Devices and Storage Corporation, Texas Instruments Incorporated, Qualcomm technologies Inc., Taiwan Semiconductor Manufacturing Company

Limited(TSMC). Share of the microprocessor market worldwide from 2018 to 2020, by vendor is shown in figure-04 [(Statista.com, 2020).

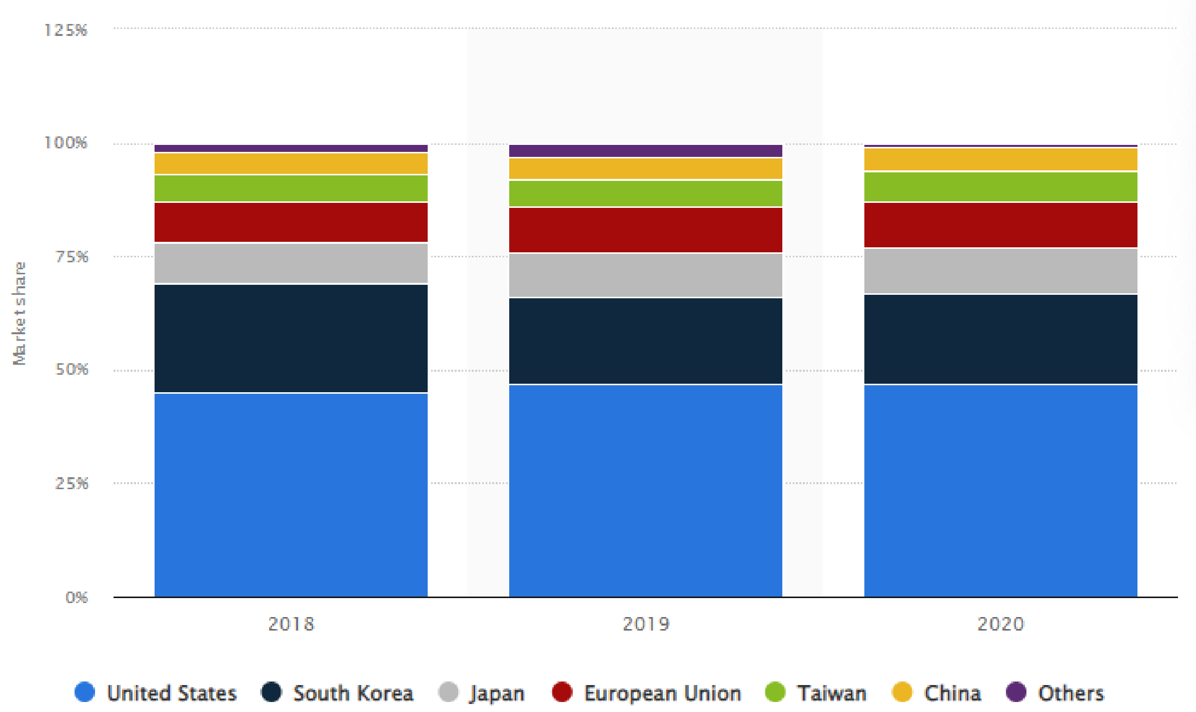

Figure 4: Share of the global semiconductor industry by country from 2018 to 2020.

Developments of new versions of the microchip is so fast that end user always get “minus 02” version for use . Latest version being in the factory and second latest in distribution. By the time this work will be published, new versions will appear in the market.

Explosive growth in online IT products and services during COVID-19 pandemic pushed the demand of the microprocessors to the breaking points. Harvard business reviews reacted to the situation in their publication “Why We’re in the Midst of a Global Semiconductor Shortage” (Bindiya Vakil, 2020).

Countries with huge present and future demands have opportunity for augmenting the supply of semiconductors / microprocessors. Availability of left-over useful life of microprocessors in discarded hardware is potential opportunity for the countries, like India struggling to learn developing their own microprocessors. Looking at the demand and supply gap on microprocessor and availability of skilled manpower in India clearly has opportunity for achieving the twin goals of maximizing availability of processing power and minimizing e-waste.

IT education in India is heavily focussed on the programming skills. Hardware seems left out. All the technical education institutions need to work on mission mode to balance the knowledge asymmetry on core hardware front.

Microprocessor Manufacturing

Microprocessors are produced primarily from silicon, the second most common element on the planet after oxygen. Impure Silicon is found on the sea beaches.

Silicon is formed into chips in a lengthy process starting from growing pure silicon crystals through Czochralski (ज़ोक्राल्स्की) process. In this method, electric arc furnaces transform the raw materials (quartz rock) into metallurgical grade silicon. Then impurities are removed by converting silicon into liquid, distilled, and then redeposited in the form of semiconductor grade rods 99.99% purity. These rods are then mechanically broken up into chunks and packed into quartz crucibles. Crucibles are loaded into electric crystal pulling ovens. Silicon chunks are melted at more than 2,500° Fahrenheit in the quartz crucibles.

After melting the silicon, a small seed crystal is inserted into the molten silicon and slowly rotated. As seed is pulled out of the molten silicon, some of the silicon sticks to the seed and hardens in the same crystal structure as the seed. By carefully controlling the pulling speed (10–40 mm per hour) and temperature (around 2,500°F), the crystal grows with a narrow neck. Then the crystal widens into the full desired diameter. Depending on the chips being made, each ingot (block) is 200 mm or 300 mm in diameter and more than 5 feet long, weighing hundreds of KG.

The ingot is then ground into a perfect 200 mm or 300 mm diameter cylinder, with a small, flat cut on one side for positioning accuracy and handling. Each ingot is then cut with a high-precision diamond saw into more than a thousand circular wafers, each less than 01 mm thick. Each wafer is then polished for mirror smooth surface.

Chips are manufactured from the wafers using a process called ***photolithography***. Transistors, circuit and signal pathways are created in semiconductors by depositing different layers of various materials on the chip, one after the other using lithographic process. Transistor or switch can be formed where two specific circuits intersect.

The photolithographic process starts when an insulating layer of silicon dioxide is grown on the wafer through a vapor deposition process. Following deposition process, a coating of photoresist material is applied, and an image of that layer of the chip is projected through a mask onto the now light sensitive surface of wafer.

Pure silicon being non-conductor, some conductors are inserted into the wafer for making it controlled semiconductor , process is called doping. Lithographic projector uses a specially created mask, which is essentially a negative image of the layer of the chip design. Mask is etched in chrome on a quartz plate. Modern processors have more than 20 layers of material deposited and partially etched away (each layer requires a mask) and up to six or more layers of metal interconnects.

As the light passes through a mask, the light is focused on the wafer surface which exposes the photoresist with the image of the layer of the chip. Each individual chip image is called a *die*. A device called a *stepper* then moves the wafer over a little bit, and the same mask is used to imprint another chip die immediately next to the previous one. Process is repeated to print many chips. After the entire wafer is imprinted with a layer of material and photoresist, a caustic solution washes away the areas where the light struck the photoresist, leaving the mask imprints of the individual chip circuit elements and pathways. Process is repeated for laying another layer on the chip. Using this method, the layers and components of each chip are built one on top of the other until all the layers are built and chips are completed.

Some of the masks are used to add the *metallization* layers, which are the metal interconnects used for tying all the individual transistors and other components together. Most of the interconnects are made of copper. Older chips used aluminium.

Another technology that is becoming common is the use of silicon on insulator (SOI) instead of Complementary metal oxide semiconductor (CMOS) technology. AMD uses SOI for its 90 nm processors, and it's expected that SOI will continue to grow in popularity due to better insulation properties.

A completed circular wafer has as many chips imprinted on it as possible. Each chip usually is square or rectangular in shape, leaving some portion of the wafer unused.

After a wafer is complete, a special fixture tests each of the chips on the wafer and marks the bad ones to be separated out later. The chips are then cut from the wafer using high powered laser or diamond saw.

After being cut from the wafers, the individual dies are then retested, packaged, and retested again. The packaging process is also referred to as *bonding* because the die is placed into a chip housing in which a special machine bonds fine gold wires between the die and the pins on the chip. The package is the container for the chip die, and it essentially seals it from the environment.

After the chips are bonded and packaged, final testing is done to determine both proper function and rated speed. Different chips in the same batch often run at different speeds. Special test fixtures run each chip at different pressures, temperatures, and speeds, looking for the point at which the chip stops working. At this point, the maximum successful speed is noted and the final chips are sorted into bins with those that tested at a similar speed. For example, the Pentium 4 2.0A, 2.2, 2.26, 2.4, and 2.53GHz are all exactly the same chip made using the same die. They were sorted at the end of the manufacturing cycle by speed.

Manufacturer gains more experience and perfects a particular chip assembly line, the yield of the higher-speed versions goes way up. So, of all the chips produced from a single wafer, perhaps more than 75% of them check out at the highest speed and only 25% or less run at the lower speeds. The paradox is that Intel often sells a lot more of the lower-priced, lower-speed chips, so it just dips into the bin of faster ones, labels them as slower chips, and sells them that way. People began discovering that many of the lower-rated chips actually ran at speeds much higher than they were rated, and the business of overclocking was born.

Pin grid array (PGA) , staggered pin grid array (SPGA), flip-chip pin grid array (FC-PGA) , FC-PGA2, single edge contact cartridge (SECC), (SECC2), single edge processor package (SEPP), single edge processor (SEP) are present day techniques used for the packaging of the microchips. (Robert Bruce Thompson, 2003) .

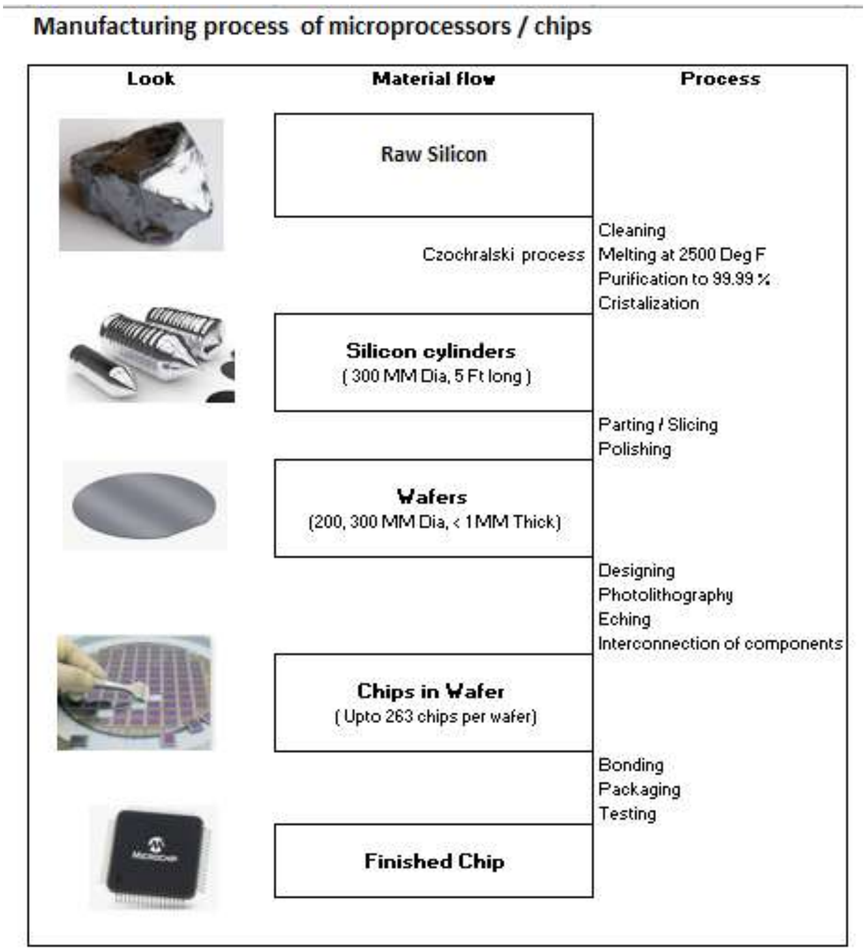

Figure 5: Manufacturing process of Microprocessor

Technologies used:
Manufacturing of the microprocessors need many high precision techniques due to involvement of very small sizes . Microprocessors need to operate at nanometre levels of the precision. Just have idea of the very small sizes involved, chips are rated at nm (10 ^ -9 M). Latest semiconductor developed by IBM has rating of 2NM. 02 NM is the distance between transistors embedded into silicon base.
Following is limited list of technologies :

- Mining and Metallurgy processes
- Crystallization
- Parting/ Slicing
- Lithography
- Etching
- Bonding & Packaging

Mining and Metallurgy processes
Mining is well settled group of technologies used in spectrum of industries converting naturally occurring ores into pure materials of Mendeleev's periodic table. Most common ingredient used in chip making is silicon while small quantities of the Nickel, Cobalt, Boron, copper, silver and Gold are also used.
Crystallization :
Crystallization is a process which happens when the materials solidify from a liquid, or as they precipitate out of a liquid or gas. This process can be carried out naturally or artificially. Crystallization process is carried out on the basis of the size and shapes of the molecules involved, and their chemical properties. Crystals can be made out of 01 species of atom, different species of ions, or even huge molecules like proteins. Some big molecules have a difficult time going through the crystallization process, as their internal chemistry is not symmetrical or interacts with itself to avoid crystallization. Preparation of silicon cylinders uses process of crystallization at very slow speed known as Czochralsky process.

Parting/ Slicing:
Parting or slicing of silicon cylinders to produce wafers is high precision sub-process. This is done by laser cutting tools or Diamond head saws.
Lithography:
Lithography is process used for printing the actual electrical circuit on the silicon wafer. Process evolved from printing the pictures initially. For example in printing images on the paper ,it makes use of the immiscibility of grease and water. In the lithographic process, ink is applied to a grease treated image on the flat printing surface. Nonimage (blank) areas holding moisture repel the lithographic ink. Inked surface retains the image. Same is then printed either directly on paper, by means of a special press (as in most fine-art printmaking), or onto a rubber cylinder (as in commercial printing).
Lithography techniques were used to print books is 19th century. Present day Kanpur and Lucknow cities were global hub for printing the books using lithography between 1840 to 1900. Detailed account of the Indian leadership in lithographic technology is compiled in Encyclopaedia Iranica (Shcheglova, 2012).
Lithography with its developed forms is key technology used for printing the miniature circuits in the chips. Most commonly used technique is photolithography.
Photo lithography:
Photolithography uses a beam of photons to transfer a pattern written on an optical mask to the substrate surface. In a complex IC process, a wafer will go through the photolithographic step in the order of 20 to 30 times. It was introduced almost simultaneously with the invention of the IC in 1959. There has been rapid developments in the technology, mainly in terms of miniaturization. Presently IC 's are manufactured on nanometre (NM) scale.
Standard lithography sequence involves many steps. The wafer is initially cleaned and heated to remove any moisture from its surface. After deposition of an adhesion promotor, photoresist(a liquid polymer) is spun on the surface while the wafer rotates at high speed.
The wafer after photoresist deposition is introduced in an optical projection tool called stepper /scanner. A light beam passing through the mask is focused on the wafer through a reduction lens system to produce the desired image in the photoresist.
In order to achieve high resolution, only a small portion of the mask is imaged once, but the small image field is repeated over the surface of the wafer by a combination of stepping and scanning operations. During exposure, the photoresist material undergoes some light sensitive chemical reactions, which cause the illuminated regions to be either more or less acidic. If they become more acidic, the material is called a positive photoresist, while in the reverse case it is a negative photoresist. The resist is then developed in an alkali solution such as sodium hydroxide (NaOH), which removes either the exposed (positive photoresist) or the unexposed (negative photoresist) polymer. After development, the wafer is finally "hardbaked" at high temperature in order to solidify the remaining photoresist. The resist can then be used as a patterning mask for etching, deposition or implantation. After patterning, the resist is stripped from the wafer with appropriate solvents.
The optical resolution of the lithography system is the main factor determining the smallest device size that can be fabricated at any time. Current state-of-the-art photolithography tools use deep ultraviolet light (DUV) with wavelengths of 248 and 193 nm, allowing feature sizes below 100 nm to be printed with good yield. Extreme ultraviolet (EUV) systems using 13 nm radiation are presently under development for introduction by the end of this decade. Because such short wavelength radiation cannot be diffracted by lens systems or absorbed by bulk masks, the EUV technology will require a transition from diffractive to fully reflective optics.
Using photolithography technique patterns are formed on the surface of the wafer needed for selective doping and formation of metal interconnects. It has three main components.
• Photoresist - light sensitive polymer
• Exposure system - irradiates photoresist through a mask
• Developer - dissolves exposed photoresist Photolithography After the photoresist is patterned, the underlying material is etched using wet or dry techniques.
Etching:
Etching is the process by which patterns are transferred into the oxide (or metal layer, as we'll see later, or even the silicon itself, in some cases). The simplest approach is to use a chemical solution that breaks down the layer to be removed. Generally, the solutions that etch best are acidic liquids. Since the wafer is being immersed in a liquid solution, this type of process is called "wet chemical" etch. Processes for "dry" etching are also in use.
Bonding and packaging:
Bonding and Packaging of ICs. The bonding and packaging of an integrated chip provide connections to the outside world. Usually, an IC can be packaged individually or incorporated into a hybrid circuit. Packaging the circuit give it some mechanical and environmental stability.
IC packaging refers to the material that contains a semiconductor device. The package is a case that surrounds the circuit material to protect it from corrosion or physical damage and allow mounting of the electrical contacts connecting it to the printed circuit board (PCB). There are many different types of integrated circuits, and

therefore there are different types of IC packaging systems designs to consider, as different types of circuit designs will have different needs when it comes to their outer shell.
ThreePin-grid array: These are for socketing.
Lead-frame and dual-inline packages: These packages are for assemblies in which pins go through holes.
Chip scale package: A chip scale package is a single-die, direct surface mountable package, with an area that's smaller than 1.2 times the area of the die.
Quad flat pack: A lead-frame package of the leadless variety.
Quad flat no-lead: A tiny package, the size of a chip, used for surface mounting.
Multichip package: Multichip packages, or multichip modules, integrate multiple ICs, discrete components and semiconductor dies onto a substrate, making it so the multichip package resembles a larger IC.
Area array package: These packages offer maximum performance while still conserving space by allowing any portion of the chip's surface area to be used for interconnection. are variety of packaging types .
Paper has just drawn the outline description of chip manufacturing. Actual manufacturing is complex, high precision and mostly the trade secret of the manufacturer.

Typical supply chain of the microprocessors:

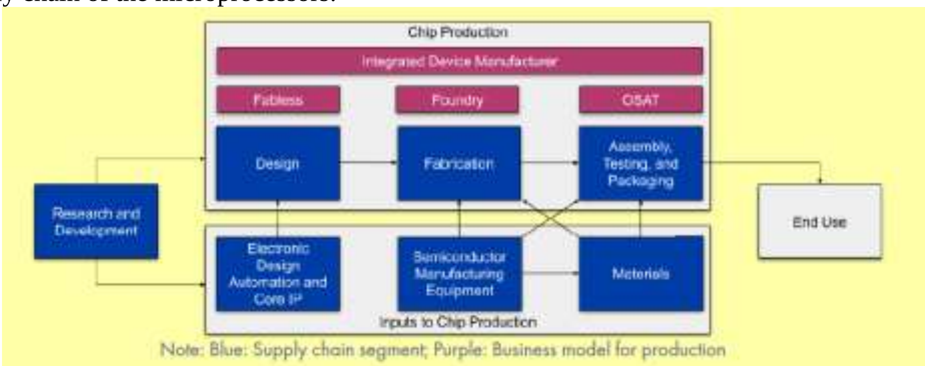

Figure 6: Typical supply chain of Semiconductor chip (Saif M. Khan, 2021)

Manufacturers of chips use facilities for undertaking mainly three sub processes either in-house 100% or outsourcing of some subprocesses. Fabless manufacturer does not involve any fabrication in-house. Foundry manufacture does physical fabrication of chips while outsources semiconductor assembly and test (OSAT).
Ingredients for Chip Manufacturing:

Abstract layer	**Tools Layer**	**Processes**	**Products or WIP**
R&D	Argon fluoride laser (Arf) dry scanners	Assembly inspection	Analog chips
Advanced Logic	Argon fluoride laser (Arf) immersion scanners	Atomic layer etch	Discrete chip
AI ASIC Logic	Assembly and packing	Bonding	DRAM chips
Core IP	CMP tools	Burn in	Logic chips
CPU Logic	Deposition	Chemical vapour deposition	Logic foundry
Design	E-beam Lithography	Dicing	Logic IDM
FPSGA Logic	EDA software	Dry etch & clean	Memory chips
GPU Logic	Etch & clean	Electrochemical deposition	NAND chips
	EUV scanners	Integrated assembly	Optoelectronics
Materials	i-line stepers	Packaging	Sensors
CMP slurries and pads	Imprint Lithography	Photomask inspection	System on a chip
Deposition materials	Ion implanters	Physical vapour deposition	Wafer
Electronic Gases	Argon fluoride laser (Arf) steppers	Process monitoring	
Fab materials	Laser Lithography	Rapid thermal processing	
Packaging materials	Mask aligners	Resist processing	
Photo resists	Process & control	Spin coating	

Photomasks	Testing	Tube -based diffusion & deposition	
Raw materials	Wafer and mask	Wafer inspection	
Wet chemicals	Handlers & probers	Wafer level packing inspection	
		Wafer manufacturing	
		Wafer marking	
		Wafer mask and handling	

Figure 7: Ingredients for Chip Manufacturing.

Raw Materials used:

Silicon

Silicon (Si) is the most commonly used material in the production of semiconductor devices because of its low raw material cost and simple manufacturing process. Silicon's ability to perform well even at high-temperatures is what makes it desirable. The silicon wafer used in semiconductor device fabrication has a diameter of 300 mm or 12 in. Silica sand goes through silicon manufacturing to produce extremely pure single crystal silicon.

Gallium Arsenide

Gallium Arsenide (GaAs) is used for high-speed devices, except that it has been challenging to create large-diameter bowls of this material, which limits the wafer diameter sizes into smaller sizes compared to silicon wafers. This makes its mass production more expensive compared to silicon.

Germanium

Germanium (Ge) used to be the most common material in semiconductor fabrication, but because of its thermal sensitivity, more companies opt for silicon. Today, germanium is combined with silicon for extremely high-speed devices.

Allied tools and technologies:

Allied tools and technologies used for manufacturing of microprocessors

Tool	**Description**	**Tool Type**	**First Leading country(s) with market share**	**Second Leading country(s) with market share**
EDP	Electronic design automation	Software	USA , 96%	Japan, 3%
Core IP	Core intellectual property	Copy right of chip design	USA, 52%	Europe, 43%
Wafers	Silicon Base for chip	Material	Japan, 56%	Taiwan, 16%
Fab Tools	Fabrication tools for chips	Machines and tools used in fabricating chips	USA, 44%	Japan, 29%
ATP Tools	Assembly, packing and testing tools	Assembly, packing and testing tools	Japan, 44%	USA, 23%

Figure 8: Allied tools and technologies used for manufacturing of microprocessors(Saif M. Khan, 2021).

Manufacturing of microprocessor in India:

India has contribution to chip manufacturing in design levels, manufacturing / fabrication has just begun at education institution, IIT, Madras. Status of chip manufacturing in India has been summarized by Union Finance Minister in her speech on 12.08.2021.

"*Finance Minister Nirmala Sitharaman on Thursday, August 12, 2021, during CII Annual Meeting, said that the industry needs to bring chip manufacturing to India in view of the global semiconductor shortage affecting manufacturing across the world. Minister also said that the industry needs to focus on a self-reliant India plan for its energy needs.*"

India needs to learn microprocessors very fast in order to achieve goal of self-reliance. Such learning can be sped-up through forward engineering, reverse engineering, and lateral engineering. Curriculum of all education centres needs alignment for teaching and learning, aspects of chip manufacturing which is multidisciplinary and wide ranging. It involves knowledge bases from the disciplines of Physics, Chemistry, Lithography, Mining, Metallurgy, Chemical, Mechanical, Electrical, Electronics and Computing. Substantial expenditure on R&D will be needed for self learning in the areas of knowledge gaps. Financing for the R&D could be arranged by monetary gains from using unused life of existing microprocessors.

Technologies use in testing, packaging and transplanting the microprocessors are to be mastered on priority.

Risks and opportunities for India
Having lost precious 50 years without active role in the development of microprocessor, a tiny core of all modern developments, India is loosing the aspiration of being "Vishvguru". Further ignorance would risk economic growth, Dependence on external suppliers, Underuse of talent and manpower, High costs and generation of e-waste. Geo-political competition and rivalry poses risk of interruption in the economic development. In the probable scenario of cyber war, critical electronic components will play vital role of soft attacks and invasions.
Monstrous size of the e-waste has now been identified as waste difficult to deal and serious environmental hazard. Researchers are now inventing ways for safe disposal of e-waste. Recycling of e-waste is being practiced widely. But size of the e-waste is growing to the sizes to unmanageable proportions.
On opportunity front, country has abundance of talent and huge perennial demand of the microprocessors. Recent political dispensation provides fertile ground to excel in the field, just like cryogenic engines.
Use of balance useful life of discarded chips gives opportunity not only for supplementing the supply but excellent raw material for the learning the craft.

Balance shelf life of the microprocessors
Developments of new versions of the microprocessors forceearly discard of the electronic devises. Marginally improved version of the electronic device supported by new version of the microprocessor motivated masses to discard old and buy new ones. Consequently, useful life of the electronic gadgets is very low as compared to its potential full life. For example, computing devices like desktop and laptop computers have mere 03- 05 years useful life. As a consequence chips used in the electronic devices also have shelf life of 03-05 years. While, microprocessors of such devices has mini. 20 years of the shelf life (Papiewski, 2021) without any problem . Same is the case with microprocessors used in smart mobile phones.
Every discarded electronic device has discarded microprocessor with it. At least 15 years of the useful life of the microprocessor is also discarded. This amounts to wasted of the 75% of the useful life. Using balance useful life of the discarded microprocessors is clearly visible opportunity for augmenting and segregation of supply of the microprocessors for speed intensive applications and normal users of the computers in India.

Latent demand

It is recently reported that 24% Indians own a smartphone, only 11% of households possess any type of computer, which could include desktop computers, laptops, notebooks, netbooks, palmtops or tablets. Even the penetration of digital technologies in India has been haphazard and exclusionary (DAS, 2020). As every computing device has a microprocessor, it can be said one third of Indian population uses at least one microprocessor and two third of the population is waiting to be no-board. Two third of population account for approximately 100 crore people. Very conservative estimate would reveal that 50 crores of the Indian population has desire to use computer but not able to afford any version of the working device, due to price barrier. There exists latent demand of at least 50 crore microprocessors immediately. Demand of computing devices is perennial due to obsolescence of the devices in use. Affluents are replacing fast and incapable are deprived. Imbalance can be bridged by reducing price and increasing life by strategic reuse.

Supply of the microprocessors is a constraint due to trade practice of keeping prices high. Following learning curve, prices of same feature of computing devise come down but such devices are discarded early for maintaining demand at same price with enhanced features. Lower versions of computing devices are de-supported and discarded. As a consequence balance useful life of the microprocessor is discarded for scrap.

All users do not need high capacity microprocessors

Mass consumers of the computing devices use varying processing capacities. There are users, who use the devices to meet low level computing requirements on day to day basis. Others are moderate to extensive users depending on the profession and software used by them. Such users can be classified into 04 classes, such as, basic users, power users, wizard users, advance and super users. As on date availability and uses of the microprocessor speed can be summarized as matrix in table No. - 04 . There is potential to introduce new user class as economy user class. Presently , deprived of any kind of computing device, economy class of users can open flood gates of demand of cheaper computing devices.

Typical demand of microprocessor capacity (GHz) *(As on Sept'2021)*

Computer Applications	Required Speed of Processor	Speed range	User Class	Price Point
Word processing	Low	< 1 GHz	**Basic Users**	**X***

Spread sheet	Low	< 1 GHz		
Power Point	Low	< 1 GHz		
E-mail	Low	< 1 GHz		
Web browsing	Low	< 1 GHz		
Media streaming	Low	< 1 GHz		
Social Media interaction	Low	< 1 GHz		
Video editing	Medium	1 - 3 GHz	**Power Users**	**3X**
3D Animation	Medium	1 - 3 GHz		
Design (CAD)	Medium	1 - 3 GHz		
Programming	Medium	1 - 3 GHz		
Gaming	High	>3 GHz	**Wizard Users**	**6X**
Machine (IoT)	High	>3 GHz		
Server	High	>3 GHz		
Forecasting	Very High	>3 GHz	**Super Users**	**> 9X**
Data centre	Very High	>3 GHz		
Super computing	Very High	>3 GHz		
Big data processing	Very High	>3 GHz		
Potential new Class of users (Deprived Class)				**Targeted**
Word processing	Low	< 1 GHz	**Eco(nomy) Users**	**X /3****
Spread sheet	Low	< 1 GHz		
Power Point	Low	< 1 GHz		
E-mail	Low	< 1 GHz		
Web browsing	Low	< 1 GHz		
Media streaming	Low	< 1 GHz		
Social Media interaction	Low	< 1 GHz		
** Lowest price for new laptop INR 30000, and Mobile phone INR 10000 per piece.*				
*** New user class can target the price point of INR 10000 for laptop and INR 3000 for Mobile phone.*				

Table 4: Typical demand of microprocessor capacity (GHz)

Market prices of new laptop or desktop today range between INR 30,000 to 3,00,000. Similarly, prices of new smart mobile phones begin from INR 10,000. These two devices share bulk of demand and supply of the microprocessors. Today, purchasing power dictates the choice of the device without any consideration of available processing capacity and required processing capacity. It is seller's market fuelled by status symbol behaviour of the buyers. New versions are introduced fast and old versions of the devices discarded without exploiting full value from the components of the computing devices , microprocessor is single costliest and underutilized component in the computing devices.

Many needy users are deprived of any kind of computing devices due to lack of purchasing power. There are scares instances of unorganized, grey markets where devices and components are traded without any guaranty or warranty. Pricing in grey market of used devices and components range from 30% to 50% of the fresh device or components. Things are available on-line too but limited and risky. Demand as well as supply do exits for the reused devices, specially for microprocessors. But skills to the utilise used devices and used components are limited to the matching of printed specifications only. Any deviation in fitment of the components makes them e-waste. Skills for the specification verification, testing, transplantation are in acute shortages.

Formal classification of the computers based on the end usage can formally establish the price points. Table – 04 above, proposes such classification. Used computers can be passed to lower end of utility , from super user to the basic user, for example. Most advance servers used microprocessor below 01 GHz clock speed prior to year 2000. Used computers and used microprocessors discarded by normal users canbe put to use for another 03 to 05 years by new class ofdeprived users "Eco(nomy)", if price point is calibrated with the usefulness of the device. Review of the current literature on prices of used components suggest such price point can be one third of the price point of fresh devices with lower end of the processing power.

Availability of Microprocessor speed drives the demand

Speed of microprocessors used in most powerful serves used to be few MHz before year 2000. While speed of chipset used in lower end desktop PC is above 01 GHz in 2020. Demand of the processor speed does not increase in the proportion of the developments in the microprocessor design. Users of normal and power class are still capable of competing their work with slower microprocessors. They always do not want the latest and fastest chip. But trade often, pushed them to contrary. Microprocessors discarded by advance users, like advance and super users can meet all the requirements of Basic class of users. Rolling supply of microprocessors from super class users to Economic class users provide opportunity to utilize useful life of the microprocessors to its maximum. There are clusters of unorganized grey markets which trade used devices informally.

Such informal business, if formalized, has huge potential for supplementing supply of microprocessors in import dependent country like India. There is similar successful business model in automobile industry. “True value “ business segment of used cars by Maruti Ltd. to imitate.

Opportunities

Latent demand for the microprocessors in India can be satiated through four supply streams. Imports, indigenous manufacturing , reuse of computing devices and reuse of microprocessors in new devices. Country has realized the need for quick action in microprocessor front, providing strong political will and support. But development of entire indigenous industry would take time, giving marginal relief in imports. Uses of microprocessors with balance self-life is low hanging fruits, computer professional and education institutions can focus immediately. Country with 3500 engineering colleges and 23 specialized IIT’s , presents excellent technical manpower base for mastering every aspect of microprocessors.

There exists immediate demand and opportunity for the skills to test the microprocessor, validate the printed specifications, documented inventory of used microprocessors, dismantling and resoldering to the mother board, minor repairs and selection of the substitute with closely matching specifications.

As most of computing devise are supplied as components, assembling is done in factories located in Indian territory. Manpower available in such factories could be readily available recourse for priority skills of testing, assembling, dismantling and transplanting the microprocessors from the mother boards. Rough estimate of 50 crores population is computer deprived class. Demand from this new class of users would drive a new industry and supplement economic growth, improve self-sufficiency, employment generation and reduction in e-waste generation.

Proof of concept for achieving low cost computing device , a laptop has been studied for it’s viability and costing. It is possible to provide laptop below INR 10,000 (cost of ownership for 05 years) to the deprived users classified as “Eco” users. Details of low cost laptop with discarded microprocessor are available in Annexure – I, as a case study. Total cost of ownership of laptop computer with reused microprocessor for 05 years time frame is one forth of that prevailing option with matching functionality. Price point of INR 10, 000 is easily achievable for a decent computing device for the mass users deprived of access to any computing device in the era of on-line education and other critical services.

Market of Microprocessors

Demand and Trend

Current Global demand for microprocessors is $427.60 Bn (INR 32.00 Lakh Crores) in year 2020. Demand is projected to grow at CAGR of 5.90 %(IndustryARC, 2020).

Demand of semiconductors in India was estimated at $ 7.0 Bn (INR 0.50 Lakh Crores) in 2011 and same was projected at $ 70 Bn (INR 5.20 Lakh Crores) in 2020. Demand growth was estimated at 22% per annum (Department of Electronics and Information Technology Ministry of Communications and Information Technology GOI, 2013).

Since there is scarcity of secondary data exclusively for microprocessors imports in India in money terms, projected value from the Government (Department of Electronics and Information Technology Ministry of Communications and Information Technology GOI, 2013) has been resented. Majority of microprocessors are imported as fitted in the electronic devices; separate valuation of the chips import is subject matter of immediate research.

Imported electronic components valued at INR 3.80 Lakh Crores in 2019. Assuming, approx. 40 % of this value constitutes semiconductor or microchips, INR 1.52 Lakh crores could be value of semiconductor import. The Indian electronic market is expected to be worthINR 25.00 Lakh Crores by 2025, growing at a CAGR of 16.60 % between 2020 and 2025, according to IESA(Indian Electronics and semiconductor

Association , 2020). Value of microchip import at the rate of 40% of imported electronic items will rest at 10.00 Lakh Crores.
India imported petroleum, crude, and its products worth over INR 09.00 Lakh Crores in fiscal year 2020. This was a decline from the previous financial year's import value of over INR 9.80 Lakh Crores in the country(Statista.com, 2020). Import of semiconductor components is expected to remain in the top 03 positions in the list of imports. Scenario may be altered for semiconductor imports by systematic intervention in the field.
Current global semiconductor crisis is clear indication that supply of chips surpassed the projected demand at global level as well as in India, too. Combined with the regular growth in demand due to enhanced automation in every sphere of lifestyle and entry of new consumers from deprived segments, one can simply say , demand of semiconductors in India is huge and perennial.

II. Conclusion

Semiconductor microprocessor chip drives the world today. Countries not having competence to manufacture the chips are lagging behind in the technology race and running at the risk of losing sovereignty to the countries or groups having control of manufacturing the chips. Country like India has huge demand of the chips, such demand can be met from three streams. Imports, re-use and indigenous manufacturing. Size of opportunity runs in INR 10 LakhCrores by 2025 in money terms. India needs to work on mission mode for acquiring, developing, and commissioning the chip manufacturing eco system. Educational entities have ignored the vital knowledge base related to chip manufacturing. Further ignorance would hinder sustenance and growth of the technological advancements in the country. Technologies of testing, assembling, and repairing needs to be developed on priority.

As skills and installation required for chip manufacturing would take time, country can develop itself as hub for re-use of microchips. There is abundance of the discarded chips with 75% balance useful life. Utilization of balance life of discarded chips has potential to cater the low-cost electronic devises for masses not able to afford at present price levels. Case study in appendix is showing proof of concept for extended use of the discarded microprocessors. Latent demand for the low cost computing devices is estimated at proximity to 50 crores. Full utilization of the chips help reduction in electronic waste and consequent pollution. Classification of the computing devise users based on the processing power demand is specific contribution.

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ANNEXURE – I

Case study

One discarded laptop has been bought from digital scarp market. Brocken parts of laptop replaced with new parts like battery, adapter, key board, and battery. Motherboard with original microprocessor chipset is used as such.
After formatting the hard disc, operating software Bharat Operating System Solutions (BOSS) is installed. OS is freely available from Centre for Development of Advanced Computing, India (C-DAC). As of now latest version of BOSS, Unnati is available free of cost. Applications similar to Microsoft Office are part of standard version of BOSS Unnati. Laptop works fine for all common applications like word processing, spreadsheet, presentation, E-mail, database, media player browsing, internet connectivity and printing etc.
There is twoways compatibility of files generated by BOSS and MS Office. Laptop meets the requirements well for the normal computing functions for an average computer user.
Security aspects of BOSS are not tested with the assumption of low risk with the eco users.

Technical Specifications of the laptop :

Sl No	Parameter	Value
1	Make	Acer
2	Model	Aspire 5100 BL-51
3	Make year	2006
4	Processor	AMD Turion ™ 62X2 Mobile technology TL-50
5	Year	2006
6	Clock speed	1.60 GHz
7	RAM	1.0 GB
8	Hard disk Make	Hitachi SCSI
9	Hard disc capacity	120 GB

Following table has comparison of cost of ownership in 05 years time frame with MS windows OS based lowest priced laptop and that with the laptop configured on BOSS OS based latop using discarded microprocessor.

Comparison of total Costs of ownership (TCO) for 05 years:

New Laptop					Reused Microprocessor and other components			
Sl No.	**Item**	**Unit**	**Cost in INR**		**Sl No.**	**Item**	**Unit**	**Cost in INR**
1	Laptop	1 No.	20000		1	Discarded Laptop	1	2000
2	Windows OS Licence per user[1]	5 years	10379		2	New Body	1	1500
3	MS Office licence[2]	5 years	5167		3	New Battery	1	1500
4	Resale value	After 05 Yrs	-5000		4	New Key board	1	600
					5	New Adapter	1	1200
					6	Assembling cost	1	1000
					7	BOSS OS	1	0
					8	Applications	1	0
					9	Miscellaneous	1	2000
		Sum :	**30546**				**Sum :**	**9800**

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2 https://www.microsoft.com/en-in/microsoft-365/buy/compare-all-microsoft-365-products-b.

Screen shots from BOSS based laptop in functional condition:

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