

40 Inventive Principles in Microelectronics

40 Inventive Principles in Microelectronics

By: Gennady Retseptor

gennadyr@avx.co.il

© 2002. Gennady Retseptor. AVX Israel Ltd. 972-2-5720128. All rights reserved.

Both Microelectronics and TRIZ emerged independently around 50 years ago in Western countries and the former USSR.

Microelectronics has been already recognized as one of the tremendous achievements of XX century. TRIZ has started its proliferation in Western countries only in the last decade.

For people working in Microelectronics it may be interesting to know how technical solutions in their scope are looking from the point of view of TRIZ. This article is the author's endeavor to make classification and summarize examples of TRIZ inventive principles in Microelectronics.

Editor's note: There is some debate about whether one becomes more creative by reading examples of creative problem solving in fields other than one's own, or if, for many people, examples in one's own field are needed to get started understanding how the 40 principles work. The editor's experience as a TRIZ teacher has been that most people need a mixture of examples from their own field and from others, so we have been very glad to publish lists of examples from many fields. (See References).

Principle 1. Segmentation/Fragmentation/Division

- A. Divide an object into independent parts.
 - *Individual dies on Si (Silicon) wafer.*
 - *Two-stage diffusion process.*
 - *Beam splitting.*
- B. Make an object easy to disassemble.
 - *Integrated Circuits (IC) and passive components assembly on Multi-Chip Module (MCM).*
 - *Multi-chip modules assembly on 'daughter' board.*
 - *'Daughter' boards assembly on 'mother' board.*
- C. Increase the degree of fragmentation or segmentation.
 - *Increase in number of gates per microprocessor chip (1.35 times per year).*
 - *Increase in number of bits per memory chip (1.5 times per year).*
 - *Increase in number of inputs/outputs (I/O) per chip and pins per package.*
 - *Sea of Lands (SOL) - ultra-high density packaging.*
- D. Transition to micro-level.
 - *Spray development and spray etching.*
 - *Sub-layers with different inherent stress at Microelectronic Mechanical Systems (MEMS).*

- *Decrease of feature size (to 0.05 microns and less).*
- *Molecular Beam Epitaxy (MBE).*
- *Atomic Layer Deposition (ALD).*
- *Nanometry.*

Principle 2. Taking out/Separation/Removal/Extraction/Segregation

- A. Separate an interfering part or property from an object, or single out the only necessary part (or property) of an object.
- *Clean rooms.*
 - *Isolation of Copper areas at wafer fab.*
 - *Separation of wafers from people.*
 - *Cluster tooling.*
 - *Single wafer processing.*
 - *Impurities segregation at Si crystal growth (CZ process).*
 - *LOCOS isolation.*
 - *Barrier for Copper diffusion prevention.*
 - *Ion separation at ion implantation.*
 - *Etch stop layer.*
 - *Polarized light microscopy.*
 - *Die separation by grooves at Chip Scale Packaging (CSP).*
 - *Electrical and visual screening.*
 - *Burn-in.*

Principle 3. Local quality

- A. Change an object's structure from uniform to non-uniform, change an external environment (or external influence) from uniform to non-uniform.
- *Temperature gradient at CZ process, epitaxy, oxidation, diffusion.*
 - *Pressure gradient at Chemical Vapor Deposition (CVD).*
 - *Selectivity and anisotropy at wet and dry etching.*
 - *Impurities concentration gradient at diffusion with diverse doping profiles: exponent, power-law, step, grade.*
 - *Depletion layer.*
 - *Field Effect Transistor (FET) with arbitrary charge distribution.*
- B. Make each part of an object function in conditions most suitable for its operation.
- *Single wafer processing: CVD, Physical Vapor Deposition (PVD), dry etching, etc.*
- C. Make each part of an object fulfill a different and useful function.
- *Buried layer with opposite impurity type.*
 - *P-n-p pocket in n-p-n substrate at CMOS IC.*

Principle 4. Asymmetry/Symmetry change

- A. Change the shape of an object from symmetrical to asymmetrical.
 - *SEMI standard for Si wafers crystallographic orientation marking: <111>, <110>, <100>.*
 - *P-n junction asymmetry.*
- B. Change the shape or properties of an object to suit external asymmetries.
 - *Anisotropic plasma etching.*
- C. If an object is asymmetrical, increase its degree of asymmetry.
 - *Increasing features aspect ratio.*

Principle 5. Merging/Combining/Composition/Integration/Agglomeration

- A. Bring closer together (or merge) identical or similar objects; assemble identical or similar parts to perform parallel operations.
 - *Subtracting images from neighboring dies for visual defects detection.*
 - *Integrated circuit.*
 - *Multi-chip module.*
 - *Giga-scale Integration (GSI).*
 - *Giga-scale System on Chip (GSOC).*
- B. Make operations contiguous or parallel; bring them together in time.
 - *Multi-beam electron writing.*
 - *Wafer level clean rooms operations.*
 - *Wafer level SMD termination [6].*
 - *Wafer level burn-in.*
 - *Wafer Level Packaging (WLP).*
- C. Agglomerate objects to Bi- and Poly- system.
 - *Bi-layers: Ti/TiN, Ta/TaN.*
 - *Chemical Mechanical Polishing (CMP).*
 - *Electrochemical Mechanical Deposition (ECMD).*
 - *Mechanical, electrical, magnet, plasma, etc. fields agglomeration.*

Principle 6. Universality/Multi-functionality

- A. Make a part or object perform multiple functions; eliminate the need for other parts.
 - *Multi-task dispensing system.*
 - *Multiple targets in sputtering machine.*
 - *Electron beam direct writing. No need for mask.*
 - *Plasma CF4 with Oxygen for both photoresist strip and surface cleaning in one process.*
 - *IC package substrate multi-function: multi-layer connection, heat dissipation, escaping I/O traces, controlled impedance, ground return.*
 - *Components packaging (tape and reel, bulk feed cassette, etc.) multi-function: components protection, transportation, and presentation to pick-and-place machine.*
- B. Use standardized features.
 - *International standards in Semiconductors and Microelectronics.*

- *Visual workmanship standards.*
- *Measurement, inspection and test equipment calibration.*
- *Specifications for incoming, in-process and final quality inspection.*
- *Specifications for functional, mechanical and environmental testing.*

Principle 7. Nesting/"Nested doll"/Recess/Embedding

- A. Place one object inside another; place each object, in turn, inside the other.
- *Clean rooms and clean areas multi-step nesting.*
 - *P-n-p pocket in n-p-n substrate for CMOS IC.*
 - *Buried layer.*
 - *Inverse conductivity type area made by diffusion or ion implantation.*
 - *Multi-layer termination structure.*
 - *Electrical tolerances nesting.*
 - *Embedded air-gap region within SOL.*
 - *Recessed contact pad at D-BGA packaging.*
 - *Embedding of integrated passives into Low Temperature Co-fired Ceramic (LTCC) substrate at CSP.*
 - *Packaging hierarchy : chip - module - card - board - system.*
 - *Micro-packaging and meso-packaging integration at MEMS: die - device - system.*
- B. Make one part pass (dynamically) through a cavity in the other.
- *MEMS micro-machines.*

Principle 8. Counterweight/Anti-weight/Weight compensation/Levitation

- A. To compensate for the weight of an object, merge it with other objects that provide lift.
- *Levitation of wafer by air or Nitrogen cushion.*
 - *Transportation of ultra-thin wafer by floating.*
- B. To compensate for the weight of an object, make it interact with the environment (e.g. use aerodynamic, hydrodynamic, buoyancy and other forces).
- *Capillary effects for cleaning and chemical treatment in trenches and vias.*
 - *Capillary action for solder drawing from tip to PCB pad.*

Principle 9. Preliminary anti-action/Prior counteraction

- A. If it will be necessary to do an action with both harmful and useful effects, this action should be replaced with anti-actions to control harmful effects.
- *Si₃N₄ masking for LOCOS.*
 - *LOCOS masking for ion implantation.*
 - *Silicon oxide and poly-silicon masking for diffusion.*

- *Resist masking for lithography.*
- *Buffered oxide etchant.*

- *Pre-cleaning before epitaxy, oxidation, diffusion, metallization, etc.*
- *Infra-red wafer surface drying before photoresist coating.*
- *Priming before polyimide or epoxy dispensing.*
- *PCB masking by tape.*

Principle 10. Preliminary action/ Prior action/Do it advance

A. Perform, before it is needed, the required change of an object (either fully or partially).

- *Substrate cleaning.*
- *Sputter target pre-cleaning.*
- *Photomask pre-cleaning.*
- *Equipment set-up.*
- *Functional tests for raw materials.*
- *Chemicals and bathes preparation.*
- *Dummy runs for CVD, PVD, CMP, etc.*
- *Pre-formed solder balls for BGA.*
- *Pre-fabricated film or tape-based interposer for chip connection to PCB.*

B. Pre-arrange objects such that they can come into action from the most convenient place and without losing time for their delivery.

- *Process flow chart.*
- *Batch route card.*
- *Set-up time decrease by using Single Minute Exchange of Die (SMED) techniques.*

Principle 11. Beforehand cushioning/Cushion in advance/Beforehand compensation

A. Prepare emergency means beforehand to compensate for the relatively low reliability of an object.

- *Design for reliability.*
- *Electrical circuit redundancy.*
- *Derating.*
- *Safety margins for elements dimensions and layers thickness.*
- *Clean room air ionization for Electrostatic Discharge (ESD) prevention.*
- *Scrubber for Hydrogen neutralization at epitaxy, CVD, plasma etching.*
- *Passivation, protection, encapsulation and stress compensation layers.*
- *Polymer collar around solder balls at BGA to extend temperature cycling reliability.*

- *Burn-in, Highly Accelerated Stress Screening (HASS), Environmental Stress Screening (ESS) for sorting out marginal parts prone to failure at infant mortality period.*

Principle 12. Equipotentiality/Remove Tension

A. In a potential field, limit position changes (e.g. change operating conditions to eliminate the need to raise or lower objects in a gravity field).

- *Tunnel effect devices.*
- *Step smoothing: local planarization, Phosphorus Silicate Glass (PSG) melting, laser ablation.*
- *ESD elimination by providing continuous discharge paths.*

Principle 13. Inversion/Reverse/“The other way round”

- A. Invert the action(s) used to solve the problem (e.g. instead of cooling an object, heat it).
- *Dark field microscopy.*
 - *Positive photoresist vs negative photoresist.*
 - *Subtractive vs additive lithography.*
- B. Make movable parts (or the external environment) fixed, and fixed parts movable.
- *Electron motion interpretation by ‘hole’ motion.*
- C. Turn the object (or process) ‘upside down’.
- *MOS structure inversion.*
 - *Lift-off lithography.*
 - *Stress-Free Polishing (SFP) as reverse process to Electrochemical Deposition (ECD).*

Principle 14. Spheroidality/Sphericity/Curvilinearity

A. Instead of using rectilinear parts, surfaces, or forms, use curvilinear ones; move from flat surfaces to spherical ones; from parts shaped as a cube (parallelepiped) to ball-shaped structures.

- *Circular Si wafer.*
- *Wafer edge rounding to prevent chipping.*
- *Step smoothing to prevent contact disruption.*
- *Rounded element features.*
- *Copper deposition in rings at partial electroplating.*
- *Micro-via drilling.*
- *J and S terminal shapes.*
- *Ball Grid Array (BGA).*
- *Octagonal window for solder ball.*
- *Cylinder and disk button packages.*

- B. Use rollers, balls, spirals, domes.
 - *Cylinder chamber with dome lid.*
 - *Spiral bawl at tape-and-reel machine.*

- C. Go from linear to rotary motion (or vise versa).
 - *Rotary motion at chemical treatment, drying, development, etching.*
 - *Bath liquid circulation.*
 - *Rotary or planetary motion at PVD, CVD, CMP, ion implantation.*
 - *Spin-Etching Planarization (SEP).*
 - *Rotary squeegee, paste rolling.*

- D. Use centrifugal forces.
 - *Spin-on resist dispensing.*
 - *Spin-on polyimide coating.*
 - *Spin-On Glass (SOG).*
 - *Spin-On Dielectric (SOD).*
 - *Spin-on sol-gel coating.*

Principle 15. Dynamics/Dynamicity/Dynamization/Optimization

- A. Allow (or design) the characteristics of an object, external environment, or process to change to be optimal or to find an optimal operating condition.
 - *Adjustable lithography exposure, development and etching time.*
 - *Adjustable coating, plating, CVD, PVD deposition rate.*

- B. Divide an object into parts capable of movement relative to each other.
 - *MEMS micro-machines.*
 - *MEMS variable capacitors.*

- C. If an object (or process) is rigid or inflexible, make it movable or adaptive.
 - *Rotary motion of ingot for better convection at CZ process.*

 - *Agitation at development, etching, stripping, electroplating.*

 - *Linear, rotary or planetary motion of wafers at CVD, PVD, CMP, etc.*
 - *X-axis nozzle scanning, Y-axis wafer scanning at scan-coating technology.*

- D. Increase degree of free motion.
 - *Ultrasonic agitation at cleaning and plating.*

Principle 16. Partial or excessive actions/Excess or shortage

- A. If 100 percent of an object is hard to achieve using a given solution method then, by using 'slightly less' or 'slightly more' of the same method, the problem may be considerably easier to solve.

- *Excessive spin-on coated material removal by centrifugal forces.*
- *Extended etch time to compensate for non-uniform layer thickness.*
- *Excessive Phosphorus removal by PSG boiling.*
- *Excessive resistor area removal by laser trimming.*
- *Excessive screen printed paste removal by squeegee.*
- *Safety margins for electrical parameters.*

Principle 17. Another dimension/Change dimension/Moving to a new dimension

- A. Move an object in two- or three-dimensional space.
 - *2D arrays for flip chip terminal ports (PGA, BGA, LGA, CGA, etc.).*
 - *2D bar-code data matrix on components and PCB.*
 - *Redistribution of ports at WLP from peripheral to array arrangement.*
 - *3D photolithography.*
 - *3D microscope.*
 - *3D X-ray board test system.*
 - *3D MEMS.*
- B. Use a multi-story arrangement of objects instead of a single-story arrangement.
 - *Multi-layer resist.*
 - *Multi-story IC structure.*
 - *Build-up Multi-layer (BUM) micro-via packaging substrate.*
 - *Multi-layer flip-chip package.*
 - *Stacked flip-chip package.*
 - *Multi-story MCM structure.*
 - *Multi-layer PCB.*
- C. Tilt or re-orient the object, lay it on its side.
 - *SMD 2-port components with reverse (long side) termination (0306, 0508, 0612).*
- D. Use 'another side' of a given area.
 - *Double-sided mask aligner.*
 - *Double-sided 'mother' PCB assembly.*

Principle 18. Mechanical vibration/Oscillation

- A. Cause an object to oscillate or vibrate.
 - *Agitation by shaking.*
 - *Random vibration testing.*
- B. Increase its frequency (even up to the ultrasonic).
 - *Ultrasonic cleaning.*
 - *Ultrasonic electroless plating.*
 - *Ultrasonic and thermo-sonic bonding.*
- C. Use an object's resonant frequency.
 - *Microwave drying for water residues removal.*
 - *Quartz resonator for coating thickness measurement.*

- D. Use piezoelectric vibrators instead of mechanical ones.
 - *Piezoelectric vibrators at spray development and etching.*
- E. Use combined ultrasonic and electromagnetic field oscillations.

Principle 19. Periodic action

- A. Instead of continuous action, use periodic or pulsating actions.
 - *Batch manufacture.*
 - *Multiple process runs.*
 - *Impulses at voltage sorting.*
 - *Temperature shock cycling.*
 - *Periodical in-process control (analysis, inspection, testing).*
 - *Periodical reliability testing.*
- B. If an action is already periodic, change the periodic magnitude or frequency.
 - *Single wafer processing at CVD, PVD, CMP, dry etching, etc.*
 - *Step-and-repeat projection lithography.*
 - *Pulsed laser cutting.*
- C. Use pauses between impulses to perform a different action.
 - *SMED techniques for set-up during process phase.*

Principle 20. Continuity of useful action/Steady useful action

- A. Carry on work continuously; make all parts of an object work at full load, all the time.
 - *Seven days a week, 24 hours a day processing at wafer fab.*
- B. Eliminate all idle or intermittent actions or work.
 - *Streamline both internal and external setups to reduce total set-up time (SMED).*
 - *Wafer level clean room processes.*
 - *Wafer level SMD termination [6].*
 - *Wafer level burn-in.*
 - *Wafer level packaging.*

Principle 21. Skipping/ Rushing through/Hurrying

- A. Conduct a process, or certain stages (e.g. destructible, harmful or hazardous operations) at high speed.
 - *Flash PVD for ultra-thin metallization layers.*
 - *Positive photoresist development time - the smaller the better.*

Principle 22. “Blessing in disguise”/“Turn lemons into lemonade”/Convert harm into benefit/Turn minus into plus

- A. Use harmful factors (particularly, harmful effects of the environment or surroundings) to achieve a positive effect.
 - *Controllable undercut.*
 - *Avalanche effect semiconductor devices.*
- B. Eliminate the primary harmful action by adding it to another harmful action to resolve the problem.
 - *Buffering anti-corrosive solution.*
- C. Amplify a harmful factor to such a degree that it is no longer harmful.
 - *Burn-in, Highly Accelerated Stress Screening (HASS), Environmental Stress Screening (ESS) for sorting out marginal parts prone to failure at infant mortality period.*

Principle 23. Feedback

- A. Introduce feedback (referring back, cross-checking) to improve a process or action.
 - *End-point detection at CMP, dry etching.*
 - *Thermostat for optimal temperature stabilization.*
 - *Test run for process parameters adjustment.*
 - *First article inspection.*
 - *In-process, final and periodical quality inspection and testing.*
 - *Statistical Process Control (SPC).*
 - *Failure Mode and Effect Analysis (FMEA), Fault Tree Analysis (FTA).*
- B. If feedback is already used, change its magnitude or influence.
 - *In-line wafer measurements using test structures.*

Principle 24. Intermediary/Mediator/Insertion

- A. Use an intermediary carrier article or intermediary process.
 - *Adhesion layer of Ti, Ta, Cr.*
 - *Barrier layer of TiW, TiN, TaN, SiN, W2N.*
 - *Adhesion promoter for coating and bonding.*
 - *Primer for polyimide or epoxy dispensing.*
 - *LOCOS masking for ion implantation.*
 - *Silicon oxide and poly-silicon masking for diffusion.*
 - *Compliant polymer layer for reducing stress under solder ball.*
 - *Chip underfill process to compensate thermally induced strains.*
 - *Interposer for chip connection to PCB.*
 - *Footprint conversion adapter for fine pitch (0201, BGA) SMD components.*
- B. Merge one object temporarily with another (which can be easily removed).
 - *Resists for photo-, deep UV, extreme UV, X-ray and e-beam lithography.*

- *Photomask.*
- *Si₃N₄ masking for LOCOS.*
- *Temporary wafer carriers.*
- *Sacrificial layer removal to leave cavity at MEMS micro-machining.*
- *Filling recess with temporary material, depositing movable charge plate and wet etching of filler at MEMS variable capacitors.*

Principle 25. Self-service/Self-organization

- A. Make an object serve itself by performing auxiliary helpful functions. *Use self-performed actions.*
- *Wafer self-masking by Si oxidation.*
 - *Auto-doping.*
 - *Impurities segregation on materials or phases border.*
 - *Gate self-alignment in MOS transistors.*
 - *Self-Ionized Plasma (SIP) directional PVD.*
 - *Etch-stop layer.*
 - *Self-assembly of micro-scale parts at MEMS.*
- B. Use waste resources, energy, or substances.
- *Deionized water (DI) water recycling system.*
 - *Use of scrapped wafers and chips for dummy runs and experiments.*

Principle 26. Copying

- A. Instead of an unavailable, expensive, fragile object, use simpler and inexpensive copies.
- *'Holes' movement model.*
 - *Virtual prototyping.*
 - *IC design and complex process modeling.*
 - *Dummy wafers and components.*
 - *Test structures.*
- B. Replace an object, or process with optical copies.
- *Photomask.*
 - *Projection lithography.*
 - *Optical comparator for component dimensions measurement.*
 - *Image processing for components visual sorting.*
 - *Pattern recognition for oriented packaging.*
 - *Color scanner Automated Optical Inspection (AOI).*
 - *Video system for pick-and-place.*
- C. If visible optical copies are already used, move to infrared or ultraviolet copies.
- *UV light for photoresist or polyimide exposure.*

- *Deep UV and Extreme UV (EUV) lithography.*
- *Deep UV reflectometry.*
- *Infrared interferometry.*
- *Infrared spectroscopic ellipsometry.*
- *Laser ellipsometry.*
- *Optoacoustics.*

- *Polarized light microscope.*
- *Photoluminescence.*
- *Spectrophotometry.*
- *Scatterometry.*
- *X-ray fluorescence (XRF).*
- *X-ray diffraction (XRD).*
- *X-ray PCB test system.*

Principle 27. Cheap short-living objects/Cheap disposables

A. Replace an expensive object with a multiple of inexpensive objects, comprising certain qualities (such as service life, for instance).

- *Single-time usage face mask, gloves, and shoes cover for clean room.*
- *Dummy wafers and components.*
- *Test PCB cards.*
- *Plastic or cartoon box, vial, bag, cassette, tape for product handling, storage and transportation.*

Principle 28. Mechanics substitution/Replacement of mechanical system/Redesigning/Replace mechanical system with fields

A. Replace a mechanical means with a sensory (optical, acoustic, taste or smell) means.

- *End-point detection at CMP and dry etching by optical reflection.*
- *Optical comparator for component dimensions measurement.*
- *Bar coding, 2D matrix data coding.*

B. Use electric, magnetic and electromagnetic fields to interact with the object. Replace mechanical devices with physical fields.

- *Electrophoretic resist coating.*
- *End-point detection methods at CMP and dry etching: plasma impedance measurement, by-products emission spectrometry, Eddy current.*

C. Change from static to movable fields, from unstructured fields to those having structure.

- *Microwave : plasma, cleaning, drying, curing.*
- *ExB plasma drift directional PVD.*
- *Glow charge dry etching.*

- *Vacuum arc deposition.*
 - *Electron beam direct writing lithography.*
 - *Scanning electron microscopy.*
 - *Laser : ellipsometry, annealing, scribing, trimming.*
 - *Laser direct writing CVD.*
 - *Pulsed laser cutting for MEMS.*
 - *X-ray : lithography, fluorescence, diffraction.*
 - *γ - Radiation for MOS and HMOS transistors threshold control.*
- D. Use fields in conjunction with field-activated (e.g. ferromagnetic) particles.
- *Magnetic field at ion separation and sputtering.*
 - *Point-cusp magnetic PVD.*
 - *Plasma : CVD, descum, anodic oxidation, sputter etching, spraying.*
 - *Ion beam : PVD, lithography, milling, sputtering, implantation.*
 - *Reactive ion etching.*
 - *Ionized directional PVD.*
 - *Electron gun for MBE.*
 - *Electron Cyclotron Resonance (ECR) plasma PVD.*

Principle 29. Pneumatics and hydraulics/Fluid system

- A. Use gas and liquid parts of an object instead of solid parts (e.g. inflatable, filled with liquids, air cushion, hydrostatic, hydro-reactive).
- *Laminar air flow at clean rooms and hoods.*
 - *Air shower.*
 - *Cascade DI water.*
 - *DI water or bath liquid turbulence by Nitrogen bubbles.*
 - *Vacuum chuck for wafer holding.*
 - *Air or Nitrogen cushion for touch-less wafer handling and transportation.*
 - *Transportation of ultra-thin wafer by floating.*
 - *Nitrogen gun for drying.*
 - *Heating or cooling fan.*
 - *Vacuum degassing.*
 - *Vacuum pick-and-place.*

Principle 30. Flexible shells and thin films/Flexible membranes

- A. Use flexible shells and thin films instead of three dimensional structures.
- *Thin-film dielectrics.*
 - *Thin-film epitaxy, oxidation, poly-silicon, metallization and other layers at planar Si wafer.*
- B. Isolate the object from the external environment using flexible shells and thin films.
- *Thin-film passivation, protection, encapsulation and stress compensation layers.*
 - *Air gap with polymer encapsulation as cushion at SOL.*
 - *Plastic bags.*
 - *Cover tape for tape-and-reel.*

Principle 31. Porous materials

- A. Make an object porous or add porous elements (inserts, coatings, etc.).
- *Multi-step air filtration at clean rooms.*
 - *Multipore filters for DI water.*
 - *Polypropilen and carbon filters for chemicals.*
 - *Porous chuck for wafer holding.*
 - *Porous tampon for marking.*
 - *Metal web baskets, barrels, sieves.*
 - *Parylene, Silicon Gel, Polymer overlay for die surface passivation.*
 - *Porous humidity consumption materials.*
- B. If an object is already porous, use the pores to introduce a useful substance or function.
- *Capillary effects for cleaning and chemical treatment in vias and trenches.*
 - *Metal web for screen printing of solder paste.*
 - *Capillary action for solder drawing from tip to PCB pad.*

Principle 32. Color change/Optical properties change

- A. Change the color of an object or its external environment.
- *Yellow light in photolithography room.*
 - *Illumination scheme for optical microscopy.*
 - *Color scanner AOI.*
 - *Colors addition-subtraction at image processing.*
 - *Polarized light microscope.*
- B. Change the transparency of an object or its external environment.
- *Anti-reflection coating.*
 - *Obscure-transparent pattern at photomask.*
 - *Fiducials, insignia, marking for multi-layer alignment.*
 - *Transparent cover glass substrate at CSP for CMOS image sensor.*
 - *Transparent tape-and-reel cover tape.*
- C. In order to improve observability of things that are difficult to see, use colored additives or luminescent elements.
- *Photoluminescence thin-film measurement.*
 - *Luminescent marking.*
 - *Fluorescent molecules at Light Emission Diode (LED) display.*
 - *Gold sputtering for SEM.*

Principle 33. Homogeneity

- A. Make objects interacting with a given object of the same material (or material with identical properties).
- *Silicon wafer polishing by colloid mixture with SiO₂ particles.*
 - *Alumina substrate grinding by colloid mixture with Al₂O₃ sand.*
 - *Silicon rubber for Si die isolation.*

Principle 34. Discarding and recovering/Rejection and regeneration

- A. Make portions of an object that have fulfilled their functions go away (discard by dissolving, evaporating, etc.) or modify these directly during operation.
 - *Resist strip.*
 - *S3N4 temporary mask removal.*
 - *LOCOS temporary mask removal.*
 - *Thick wafer backside grinding after processing, handling and transportation at clean room operations.*
 - *Temporary wafer carrier discarding.*
 - *PCB masking tape removal.*
- B. Conversely, restore consumable parts of an object directly in operation.
 - *DI water recycling system.*
 - *Self-sharpening cutting blades.*

Principle 35. Parameter change/Changing properties/Transformation of physical and chemical states

- A. Change an object's physical state (e.g. to a gas, liquid, or solid).
 - *Liquid - solid transformation of resist, polyimide, coating layers.*
 - *Liquid Oxygen, Nitrogen.*
 - *Solid diffusion sources.*
- B. Change the concentration or consistency. Use rheological liquids.
 - *Exposure to dilute Silane for Silicide passivation.*
 - *Encapsulation glue.*
 - *Screen printable paste.*
- C. Change the degree of flexibility.
 - *Damping of vibration for precise equipment.*
 - *Air gap with polymer encapsulation as cushion at SOL.*
- D. Change the temperature.
 - *Decreased process temperature by use of plasma at PECVD.*
- E. Change the pressure.
 - *Low pressure CVD.*
 - *Vacuum at PVD, ion implantation, dry etching.*
 - *High pressure CVD.*
 - *High pressure oxidation.*
 - *Variable Argon pressure at sputtering for sub-layer stress control (MEMS).*

Principle 36. Phase transitions/Use of phase changes

- A. Use phenomena occurring during phase transitions (e.g. volume changes, loss or absorption of heat, etc.).

- *Liquid - solid phase transition at CZ process.*
- *Gas - solid, liquid - gas - solid and solid - gas - solid phase transition at oxidation, epitaxy, CVD, PVD, diffusion, ion implantation.*

Principle 37. Thermal expansion

- A. Use thermal expansion (or contraction) of materials.
 - *Thermal expansion drive at variable MEMS capacitors.*
- B. If thermal expansion is being used, use multiple materials with different coefficients of thermal expansion.
 - *Leaf spring thermostat.*
 - *Bi-metallic sensor.*

Principle 38. Strong oxidants/Enriched atmosphere/Accelerated oxidation

- A. Replace common air with oxygen-enriched air.
 - *Si oxidation by wet Oxygen.*
 - *Diffusion enhancement by wet Oxygen.*
- B. Replace enriched air with pure oxygen.
 - *Si oxidation by high pressure dry Oxygen.*
- C. Expose air or oxygen to ionizing radiation.
- D. Use ionized oxygen.
 - *Oxygen plasma descum.*
 - *Anodic arc plasma oxidation.*
 - *Plasma ashing (CF₄ with Oxygen) for photoresist removal.*
- E. Replace ozonized (or ionized) oxygen with ozone.
 - *UV-Ozone dry cleaning.*
 - *Ozone at reactive ion etching.*

Principle 39. Inert environment/Inert atmosphere

- A. Replace a normal environment with an inert one.
 - *Clean rooms.*
 - *Deionized water.*
 - *Teflon jigs and cassettes.*
 - *Desiccators.*
 - *Nitrogen turbulence of rinsing water.*
 - *Nitrogen drying gun.*
 - *Nitrogen atmosphere at photoresist exposure.*
 - *Nitrogen atmosphere at polyimide exposure, drying, curing.*
 - *Argon or Nitrogen atmosphere for wafer storage.*
 - *Hermetically closed plastic bags.*
- B. Add neutral parts, or inert additives to an object.
 - *Argon at magnetron sputtering.*

Principle 40. Composite materials

- A. Change from uniform to composite (multiple) materials.
- *Silicon-on-Insulator (SOI).*
 - *Silicon-on-Sapphire (SOS).*
 - *Binary metallization alloys.*
 - *Inorganic resist - polymer bi-level scheme lithography.*
 - *Silicon Oxynitride composite dielectric.*
 - *Sol-gel dielectrics.*
 - *MOS, HMOS, CMOS structures.*
 - *Compound semiconductors.*
 - *Hetero-structures.*

References

1. Domb, E., '40 Inventive Principles With Examples', TRIZ Journal, July 1997. See also:
Business Examples: The TRIZ Journal, September 1999
Social Examples: The TRIZ Journal, June 2001
Architecture Examples: The TRIZ Journal, July 2001
Food Technology Examples: The TRIZ Journal, October 2001
Software Development Examples: The TRIZ Journal, September and November, 2001
2. Sze, S.M., 'VLSI Technology', Bell Laboratories, Inc. New Jersey, 1983.
3. 'Semiconductor International': www.e-insite.net/semiconductor.
4. 'Electronic Packaging & Production Professionals': www.e-insite.net/epp.
5. 'Electronic Components News': www.e-insite.net/ecnmag.
6. US 6,144,547, 2000. Miniature surface mount capacitor and method of making same.

About the author:

Gennady Retseptor received M(Sc) degree with honors from Moscow Steel and Alloys University, Semiconductor Materials and Devices Faculty in 1972 and has 27 years experience in Microelectronics, including 16 years in USSR (Semiconductors) and 11 years in Israel (Electronic Passive Components). He has two USSR patents and one US patent (reference [6]).

Gennady Retseptor is currently Quality Assurance Manager of AVX Israel Ltd, facility of AVX Corporation.