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ENGINEERING DESIGN UTILIZING AI-ENHANCED SOFTWARE SYSTEMS. (Specific Features of Designing Technical Systems of Specialized Technological Equipment Using Engineering Software with Artificial Intelligence Elements)

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Abstract

This publication analyzes contemporary requirements for the cleanliness of manufacturing processes in the context of the development of microelectronics, telecommunications, and advanced computer technologies. It examines the inherent contradiction between increasingly stringent environmental regulations and the need to reduce production costs, while emphasizing the existence of a minimum threshold of purification parameters below which the technological process becomes uncontrollable and directly affects the quality of manufactured products.

The limitations of the traditional approach – based on the continuous refinement of chemical reagents and the intensification of cleaning processes – are highlighted, particularly in resource-intensive industries such as the food industry, where water preparation and wastewater regeneration account for a significant share of production costs.

Special attention is given to the transformation of the innovation industry in the era of artificial intelligence and neural networks. The shift of venture capital from rapid-exit strategies toward a sustainable growth model (Scale-Up Nation) is emphasized, where Net Revenue Retention (NRR) becomes a key performance indicator. A new paradigm of the innovation industry is emerging – not merely as a generator of ideas, but as a provider of critical technological infrastructure for the global economy.

Keywords: *Technical system; Engineering software; Design of technical systems; Scientific and technical information; Key directions of technological development; Cleanliness of the manufacturing process; Criteria for achieving the Ideal Final Result (IFR); Quality of the production technological process; Environmental protection; Active substances and chemical cleaning agents; Process of modification of chemical reagents used in cleaning technologies*

Innovative Strategy for the Development of a Semiconductor Wafer Cleaning Production Module: A Systemic and TRIZ-Based Approach

Let us consider, as an example, the development process of a production module for cleaning 300 mm semiconductor wafers.

We now proceed to the analysis of a real innovative strategy within this technological field and to the question of what is more reasonable under current conditions: to continue improving surfactants and chemical cleaning agents, or to seek an innovative pathway for solving existing problems.

Moreover, it is difficult to determine whether the modification of chemical reagents used in wafer cleaning technologies constitutes a true innovation process, or whether – according to the criteria of achieving the Ideal Final Result (IFR) – such modifications solve one problem while simultaneously creating several new ones.

As innovation projects become more complex, automated design methods and systems gain increasing importance. Their significance is substantially enhanced when elements of artificial intelligence are incorporated, fundamentally transforming conventional automated design methodologies.

Only through their application does it become possible, within acceptable cost and time constraints, to complete an innovation project while incorporating heuristic elements generated during brainstorming processes.

1. Systemic Approach

The systemic approach reflects and develops the dialectical principles of "universal interconnection" and "development," and is essentially one of the principles of the dialectical method of cognition.

The methodology of the systemic approach requires representing any object as a system and examining it comprehensively.

2. System

A system is a complex of elements organized закономерно in space and time, interconnected and forming an integral unity.

A system is characterized by:

- Composition of elements;
- Structure;
- Function.

Modern computer control and monitoring systems, along with various combinations of their supervisory activity, significantly enhance the concept of a system by adding analytical capabilities and functional completeness.

3. Elements

Elements are relatively indivisible parts of a whole – objects that collectively form a system.

An element is considered indivisible insofar as a specific system quality is preserved.

For elements, the most typical process is innovative modification and optimization, which may result in a technical solution meeting the four criteria of an invention.

4. Structure

Structure is a stable and regular relationship between system elements, reflecting:

- Form;
- Arrangement;
- Nature of interactions.

Structure makes a system a qualitatively defined whole, distinct from the sum of the qualities of its elements, because interaction occurs selectively through specific properties rather than in their entirety.

5. Function

Function is the external manifestation of the properties of an object (element) within a given system of relationships; a specific mode of interaction with the environment.

Systems typically possess multiple functions.

6. Subsystems (Local Independent Systems)

Subsystems are parts of a system representing either arbitrarily or naturally identified groups of elements.

Subsystem identification is typically performed based on functional criteria.

An element may coincide with a subsystem or belong simultaneously to multiple subsystems.

The nature of relationships within subsystems differs from relationships between subsystems.

Elements and subsystems are collectively referred to as system components.

7. Supersystem (Meta-System)

A supersystem is a higher-order system within which the given system functions as a subsystem.

In such hierarchical structures, functions are controlled and managed by automated control and monitoring systems implemented via programmable controllers or processors.

This integration substantially expands system capabilities.

8. Technical System (TS)

A technical system is an artificially created material unity of elements organized in space and time and interconnected, whose functioning is aimed at satisfying a specific social need.

Elements of a technical system (TS) may be either artificial or natural. Any TS exists within two systems of relationships. On the one hand, it is an object of the material world, subject to the laws of nature (primarily the laws of physics as the most fundamental). On the other hand, a TS functions as an element of social relations, since technology serves as a means for achieving social objectives.

If a TS is characterized primarily by the spatial arrangement of its elements, it represents a device or a substance. If a TS is characterized by the organization of elements over time, it represents a method. Today, both variants are actively combined with programmable processors or controllers.

The concept of a TS makes it possible to formulate the principal feature of a technical solution (TSol): a technical solution specifies a particular technical system whose functioning enables the achievement of a defined objective, that is, it establishes the relationship between the technical system and a specific goal.

1. Aerodynamic and hydrodynamic devices forming a uniform flow of deionized water distributed across the bottom of a centrifuge. An aerodynamic foam-generating unit. An aerodynamic and hydrodynamic cleaning foam generator.

2. These autonomous technical systems may each be classified individually as subsystems and, collectively, as a single integrated supersystem.

3. Taking into account the requirement to meet the four criteria of an invention – particularly the criterion of non-obviousness – each of the above solutions at the subsystem level may be regarded as inherently non-obvious (assuming recognition of each solution as an invention). Most importantly, the supersystem represents a non-obvious combination of subsystems, in which the novel and non-obvious feature lies in the coaxial arrangement of the foam generators and their equivalents, in combination with conventional and obvious solutions for wafer gripping and insertion into the processing zone.

4. Since each of the above technical systems incorporates a processor regulating pressure, flow rate, temperature, movement speed, and other direct and indirect parameters, and given that such regulation is flexible and may be performed remotely, the classification of both the subsystems and the integrated supersystem may be presented as follows:

5. Technical system – according to the classical methodology of definition, each subsystem may be considered a technical system, and the system integrating these subsystems may be considered a supersystem.

6. Local technical system – each subsystem within the integrated supersystem may simultaneously be regarded as a local technical system, since its functions and operations occur within the confined working space of the integrated supersystem. At the same time, each subsystem individually and the aggregate system as a whole possess the property of non-obviousness.

7. Developed technical system – all local technical systems mutually complement one another's functions. The integration of local functions within the supersystem enables the formation of complex functional capabilities, thereby developing and establishing an integrative technical characteristic of the supersystem, which remains non-obvious to an average specialist in the field. Accordingly, the principles of integration allow the system to be classified as developed, at minimum due to the non-obvious integrative combination of subsystem output parameters.

8. Global technical system – the presence of a programmable processor-based structure for control, regulation, and active monitoring, combined with the ability to transmit all

operational data to the Internet and the clearly defined capability for remote operation, permits classification of this comprehensive integrative solution as a global technical system.

9. Smart technical system finally, the existence of a hierarchy of programmable controllers and processors performing real-time monitoring, adjustment, and regulation of parameters, with the capability of remote programming and reprogramming, collectively establishes the conditions under which the technical system may be classified as a smart technical system.

Let us now turn to the development stage and consider a systemic operational configuration for the efficient cleaning of 300 mm semiconductor wafers of minimal thickness.

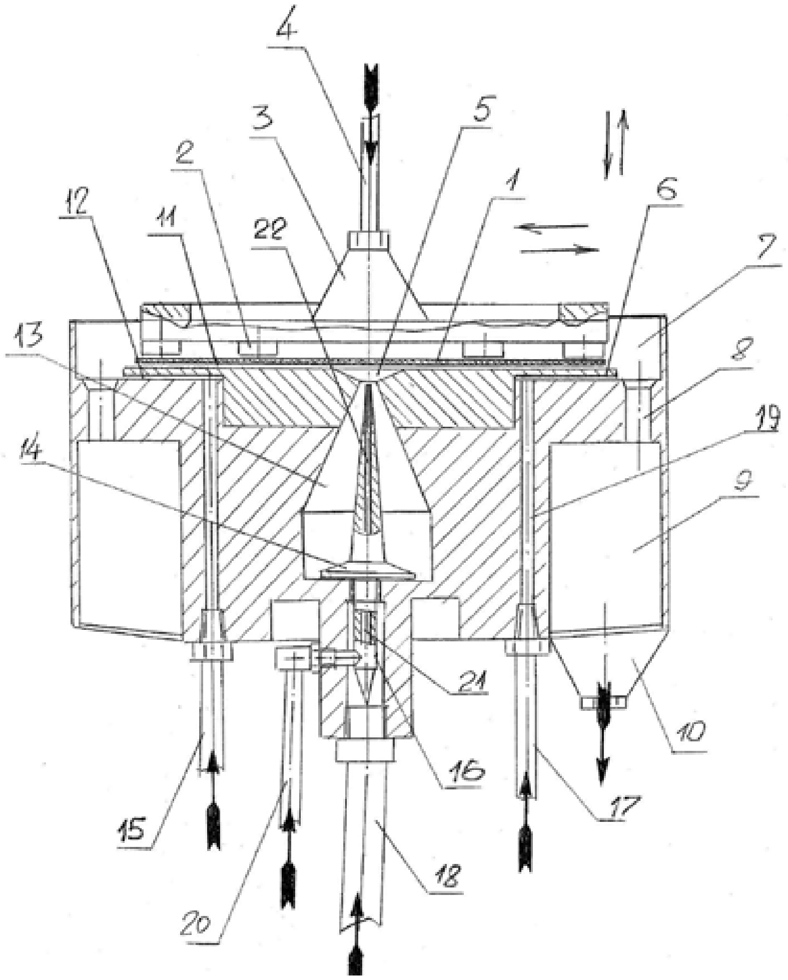
Of particular importance and value to the design process are approaches that introduce innovative elements at the subsystem level in the form of specific technical solutions, thereby transforming a subsystem into a supersystem.

It should be noted that under current conditions, all of the above must be examined in close functional interaction with control and monitoring functions delegated to the technical system through programmable controllers or processors. For comprehensive analysis and proper evaluation, it is also necessary to take into account the level of sophistication of the software systems and their degree of integration into the overall architecture of the technical system.

At the same time, the heuristic capabilities developed and articulated at levels determined by the qualification and talent of the project's lead specialist should not be disregarded.

Since different design schools exist, and their methods and approaches to system design do not always coincide, their influence on the final result may also be substantial.

Figure 1. *The figure illustrates the working centrifuge of a 300 mm semiconductor wafer preparation system intended for photolithography processes, with detailed explanatory annotations*



The numbered elements in the figure are as follows:

1 – Semiconductor wafer with a diameter of 300 millimeters

2 – Aerodynamic gripper

3 – Non-contact aerodynamic gripping system

4 – Pipeline for supplying purified compressed air

5 – Cone for uniform distribution of foam across the wafer surface

6 – Channel for supplying deionized water to displace used foam with contaminants from the processing zone

7 – Working chamber (centrifuge bath)

8 – Openings for drainage of used foam containing removed contaminants

9 – Collection reservoir for used foam and waste

10 – Bottom outlet nozzle of the centrifuge for waste drainage

11 – Gap between the processed side of the semiconductor wafer and the centrifuge table

12 – Gap between the centrifuge table and the centrifuge housing

13 – Conical cavity for foam formation and delivery into gap 11

14 – Aerodynamic foam generator

15 – Nozzle for supplying deionized water

16 – Inlet conical reflector of the foam generator

17 – Nozzle for supplying deionized water

18 – Nozzle for supplying purified compressed air

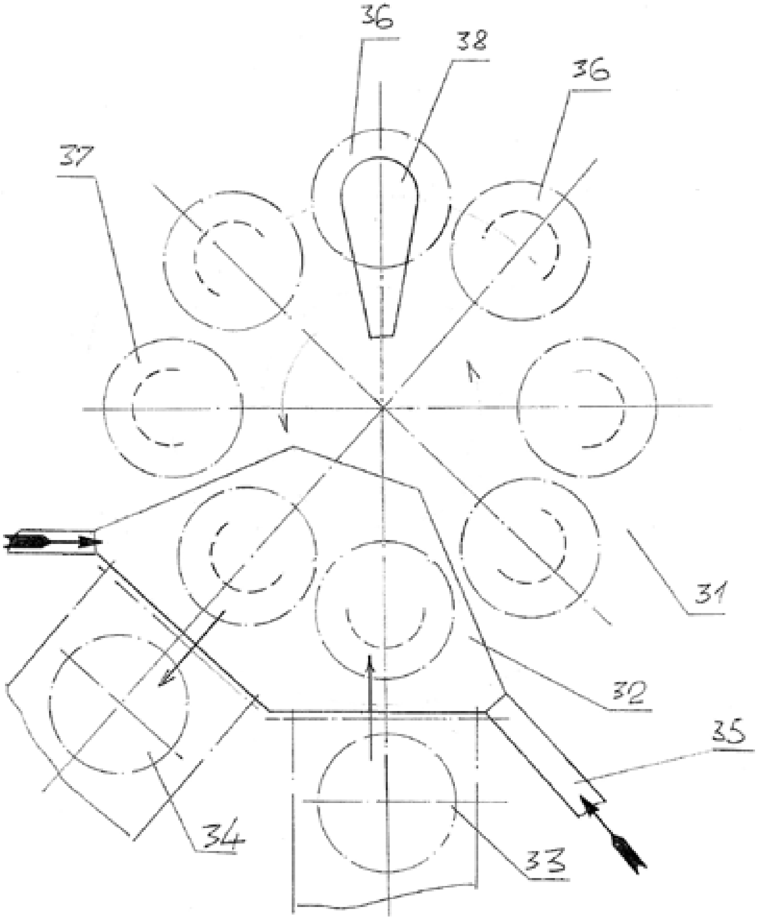
19 – Pipelines for supplying deionized water

20 – Nozzle for supplying cleaning solution

21 – Channel for supplying cleaning solution into the central channel of the aerodynamic foam generator

22 – Channel for introducing cleaning solution into cone 5

Figure 2. *The figure presents the general block diagram of a carousel-type system for preparing semiconductor wafers for photolithography processes.*



The numbered elements in the figure are as follows:

31 – Carousel with eight working positions

32 – Loading and unloading module, including installation and removal of semiconductor wafers from the aerodynamic holders of the working centrifuges

33 – Semiconductor wafer loading system

34 – Processed wafer unloading system

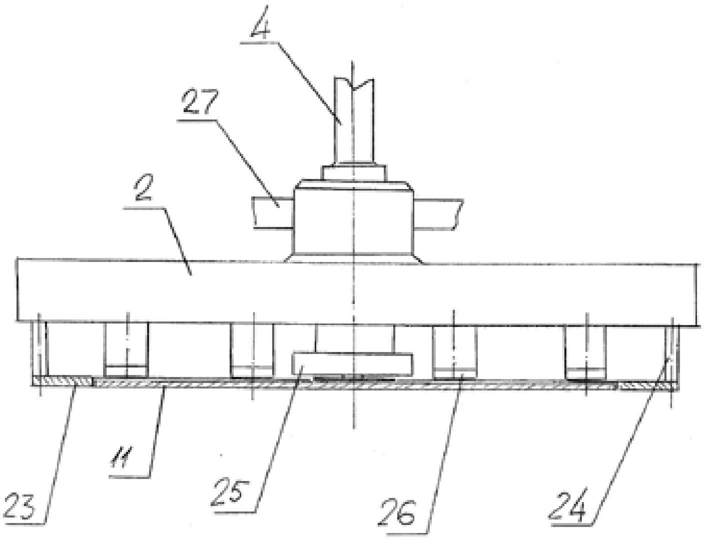
35 – System for supplying laminar purified airflow to the loading and unloading units

36 – Centrifuges positioned before the working station

37 – Centrifuges positioned after the working station

38 – Non-contact aerodynamic gripping system

Figure 3. *The figure illustrates a fundamentally new type of gripping mechanism for a 300 mm semiconductor wafer*



The numbered elements in the figure are as follows:

2 – Support plate (disc) of the gripper

4 – Nozzle for supplying purified compressed air (which does not disturb the laminar downward airflow of the cleanroom environment in which the equipment is installed)

11 – Semiconductor wafer with a diameter of 300 millimeters

23 – Annular protector preventing edge effects along the perimeter of the wafer

24 – Pins supporting and positioning the annular protector

25 – Central aerodynamic gripper operating on the Bernoulli principle

26 – Peripheral aerodynamic grippers operating on the Bernoulli principle

27 – Structural element of the robotic arm carrying and operating the gripper within the system, whose operational cycle represents the Ideal Final Result of implementing a combination of inventions for wafer alignment, gripping, transportation, and fixation during both transfer and processing, combined with edge-effect protection and mitigation of micro-deformations of the wafer.

In addition to purely structural considerations, it is also necessary to address technological materials, methods, and techniques, since collectively they may significantly complicate the processes of integration and implementation of the new development.

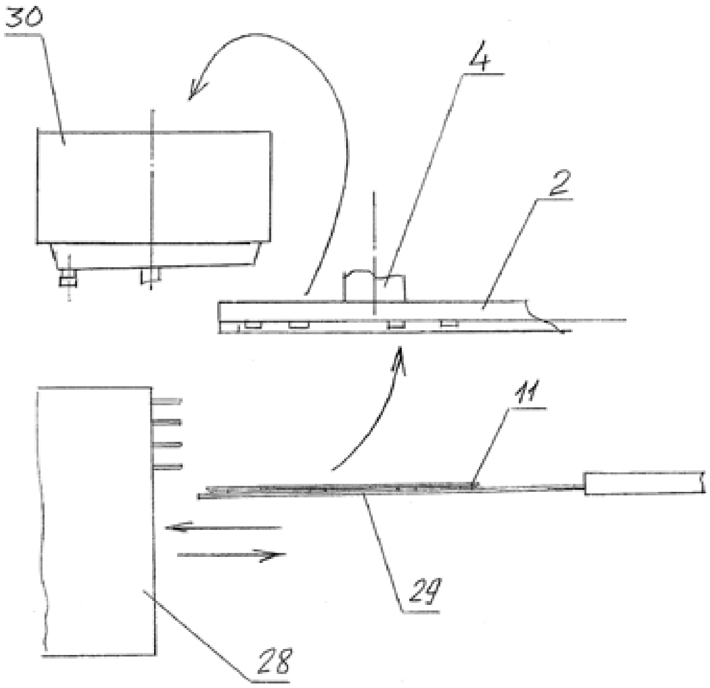
First, it is advisable to analyze the feasibility of using so-called temporary composites as components within the chemical complex employed to activate the cleaning process.

Since the cleaning process in the developed working station is carried out using a special foam produced by an aerodynamic foam generator with the capability of extremely precise control of bubble diameter and stabilization of foam parameters without the use of chemical activating or stabilizing agents, these factors must be systematically taken into account during the design and structural analysis and in the formation of the future technical characteristics of the working station as a technical system.

These considerations must also be reflected in the development of computer models of the devices that collectively form the working station and simulate the cyclic variation of its functions and real-time operational parameters.

The ability to obtain reliable predictions of expected operational parameters and performance characteristics without the need to manufacture and test a physical prototype represents one of the most significant distinguishing features of the modern engineering process. It establishes computer modeling as a central element of the design workflow and of the comprehensive end-to-end process of developing an innovative technical system.

Figure 4. *The figure illustrates the operational scheme of the wafer loading and unloading system at the working station, using the fundamentally new gripping mechanism shown in Figure 3*



The numbered elements in the figure are as follows:

2 – Support plate (disc) of the gripper

4 – Nozzle for supplying purified compressed air (without disturbing the laminar downward airflow of the cleanroom environment)

11 – Semiconductor wafer with a diameter of 300 millimeters

28 – Wafer cassette

29 – Fragment of the loading/unloading robot arm

30 – Photolithography line working station

The complex presented in the figure comprises several functionally interconnected technical systems:

- The wafer gripping system, functioning as a supersystem, which includes the following subsystems: sensor units; peripheral aerodynamic grippers; a central aerodynamic gripper; and an air supply, monitoring, and regulation system;
- The wafer cassette with integrated loading and unloading system;
- The loading/unloading robot, including all mechanical assemblies, electronics, and computer control systems;
- The working station complex, including all its constituent subsystems.

This message does not contain information about a complete production cycle involving the use of the specified mutant materials, nor does it explain what should be done with the substances that simulate and generate the magnetic properties of washing liquids after the completion of the process.

The message describes a traditional and commonly used approach to solving problems related to the washing and purification of technological solutions, including water. However, it may also be reasonable to consider the existence of an alternative innovative approach that completely eliminates the use of chemical reagents while ensuring an equivalent level of washing and purification quality.

Let us once again analyze the real necessity of using reagents and, by determining the criteria for such necessity, examine which of the known non-obvious methods of preparing technological solutions may prevent the need for chemical reagents while still guaranteeing the required level of quality.

Thus, what could replace the effect of, for example, acids or alkalis on water when such treated water is used in a production process?

As is known, during such treatment the acidity or alkalinity level of water changes, making it more chemically active, which in turn helps make the process of its use more efficient and productive.

However, there are known methods for measuring the acidity and alkalinity of water or aqueous solutions without the use of chemical reagents.

Presented below is an additional real and operational invention that allows the acidity or alkalinity of water to be changed directly within the flow, solely through an electrochemical reaction.

Today, the main software system most suitable for innovative engineering design is **SolidWorks**.

SolidWorks is a computer-aided design system used for engineering analysis and manufacturing preparation of products of any complexity and purpose. It represents a software environment intended to automate the design of complex products in mechanical engineering and in other industrial sectors.

SolidWorks is a hybrid (solid and surface) parametric modeling system designed for the creation of parts and assemblies in three-dimensional space (3D design), as well as for the preparation of engineering and technical documentation.

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