

## Innovation development trends of ceramic technology based on patent analysis

Ji Lei<sup>a,\*</sup> and Wang Xiaofan<sup>b</sup>

<sup>a</sup>Dean's Office, The First Affiliated Hospital of Henan University of Science and Technology, Luoyang, 471000, China

<sup>b</sup>School of E-commerce Logistics, Luoyang Vocational and Technical College, Luoyang, 471000, China

This study investigates the innovation development trends in ceramic technology through an extensive patent analysis. In response to the growing need for reliable data on technological activities across sectors, patent analysis has emerged as a powerful tool to track and measure innovation. The ceramic industry, known for its applications in manufacturing, electronics, and biomedicine, serves as the focal point of this research. Utilizing data from key patent databases, including the European Patent Office (EPO), the United States Patent and Trademark Office (USPTO), and the World Intellectual Property Organization (WIPO), the study examines patent filings over the last two decades. Metrics such as patent filing trends, technology clustering, geographical distribution, and top innovators are employed to reveal the dynamics of ceramic technology advancements. In addition to patent data, the Literature-Based Innovation Output (LBIO) method is incorporated, which identifies innovations from technical and trade journals. This method captures innovations, particularly those not typically patented, providing a broader perspective on the industry's innovation output. Findings suggest a significant increase in innovations, especially in structural ceramics, electronic ceramics, and bioceramics, with contributions from leading firms and academic institutions worldwide. However, limitations in patent data, such as the focus on product over process innovations, are addressed. The research offers valuable insights into the evolving landscape of ceramic technology, highlighting key innovators, global trends, and the impact of emerging technologies such as nanotechnology. The study's findings contribute to a deeper understanding of ceramic innovation trends and inform strategic decision-making for industry stakeholders.

**Keywords:** Ceramic industry, Structural ceramics, Electronic ceramics.

### Introduction

The growing emphasis on understanding technological activities in various sectors can be attributed to two key factors. First, there is an increasing demand from governments, companies, and academic institutions for reliable data on technological and scientific endeavors that receive substantial public and private investment. Second, advancements in information technology have opened up new avenues for analysis. This shift has fostered a rising interest in developing indicators for technological innovation, which are now utilized at national, sectoral, and organizational levels for diverse objectives. At the organizational level, innovation indicators help identify firms that are pioneering in their approaches, serving as a foundational step for studying their behaviors and outcomes [1].

Traditionally, assessments of a firm's technological innovation have relied heavily on metrics such as R&D expenditure and patent data. However, recent decades have introduced new indicators that focus more on innovation output, derived from direct information provided by firms as well as alternative sources like

expert evaluations and historical analyses. Previous research has explored the reliability of various innovation indicators in defining a firm's innovativeness. Yet, each indicator presents distinct strengths and weaknesses based on the specific conditions and characteristics of the collected data [2].

This study aims to analyze innovation development trends in ceramic technology through a comprehensive patent analysis. Recognizing that technological accumulation varies significantly across industries, we focus specifically on the ceramic sector. By examining a broad spectrum of innovation indicators tailored to this industry, we aim to uncover insights that reflect the unique dynamics of ceramic technology advancements. We will assess the consistency of these indicators against data from established sources, contributing to a deeper understanding of innovation within the ceramic industry and enhancing strategic decision-making for stakeholders. The study will culminate in a comparison of our findings with existing literature, offering a nuanced perspective on innovation trends in ceramic technology [3].

The use of patents as a tool for protecting innovations has long been a cornerstone of technological progress, with patent data serving as a key resource for analyzing innovation trends. Patents are publicly available records that can be utilized to trace technological advancements,

\*Corresponding author:  
E-mail: 601585639@qq.com

providing valuable insights into the innovation capabilities of firms and sectors. Numerous studies have leveraged patent counts to examine differences in technological competencies across industries and to evaluate international competitiveness. However, while patents are often used to measure innovation output, they primarily reflect inventions rather than commercially successful innovations, posing limitations as a sole indicator of technological progress [4].

Patents vary in terms of technological complexity and economic significance, making direct comparisons challenging. Additionally, disparities in patenting practices across countries and industries further complicate the interpretation of patent data. While some technological advancements remain unpatented, companies may use alternative methods to protect their innovations, such as trade secrets. To enhance patent analysis, two key indicators - innovation counts based on patented inventions and patent citation analysis - have been developed. These indicators aim to provide a deeper understanding of the economic value of patents by assessing their commercial success or influence on subsequent technological developments. Despite these efforts, both indicators have limitations, particularly when it comes to capturing unpatented innovations and fully evaluating the broader impact of technological contributions [5].

### **Identification of Innovations in Ceramic Technology Through Patent Data and Literature-Based Innovation Output (LBIO) Method**

The literature-based innovation output (LBIO) method has emerged as a valuable tool for identifying technological innovations across various industries by analyzing information disseminated in technical and trade journals. This approach focuses on gathering data about innovations reported in specialized journals, under the assumption that companies are motivated to publicize their new products and services through these publications as they approach market launch. The methodology involves systematically reviewing journals that feature sections dedicated to innovations, ensuring that only credible and editorially reviewed content is included, while advertisements are excluded [6].

The LBIO method has been successfully implemented in several countries, including the United States and across Europe. It provides a robust alternative to traditional firm-level surveys, offering insights into innovation complexity and product development without relying on self-reported data from company managers. Additionally, this approach is particularly effective in identifying innovations from small businesses, which may not typically apply for patents or participate in surveys. By focusing on published data, researchers can analyze past innovations and track trends over time,

making it a cost-effective and accessible method for innovation analysis [7].

While the LBIO method offers numerous advantages, such as ease of access to innovation data and applicability to products that are rarely patented (e.g., software), it is primarily focused on product innovations. Process innovations, unless they are part of a product launch, are less likely to be captured using this method. Moreover, the reliance on specialized journals may introduce variability in the coverage of innovations across different countries or sectors, posing challenges for international and cross-sectoral comparisons.

In the context of ceramic technology, analyzing patents and journal-based innovation reports offers valuable insights into technological advancements and emerging trends. By examining how innovations in ceramics are documented and protected, this research aims to uncover the development patterns and innovation trajectories that shape the industry.

The study employs a patent analysis approach to examine trends in ceramic technology innovation. Data was collected from major patent databases such as the European Patent Office (EPO), the United States Patent and Trademark Office (USPTO), and the World Intellectual Property Organization (WIPO). The search included patents filed over the past two decades, covering a broad range of ceramic technologies including manufacturing processes, material compositions, and applications across various industries.

Key metrics used in the analysis include:

1. Patent Filing Trends: The number of patents filed over time, showing the growth or decline in innovation activities.
2. Technology Clustering: Grouping patents based on specific ceramic technologies, such as electronic ceramics, and bioceramics.
3. Geographical Distribution: Analysis of patent filings by region to understand the global spread of innovation in ceramics.

Top Innovators: Identifying leading companies, institutions, and inventors contributing to ceramic technology development.

### **Patent Filing Trends**

The analysis shows a steady increase in patent filings related to ceramic technologies over the past 20 years. Notable peaks are observed during periods of major technological breakthroughs, such as the development of nanoceramics and bioactive ceramics. This upward trend reflects the growing importance of ceramics in cutting-edge applications and the industry's commitment to innovation.

Several key areas of ceramic innovation have been identified from the patent analysis, including:

**Advanced Manufacturing Techniques:** Ceramic technology has experienced significant advancements through the development of advanced manufacturing

techniques. Among these, additive manufacturing (3D printing), precision casting, and automated production processes have played a pivotal role in transforming the ceramic industry. These technologies have not only improved production efficiency but also allowed for unprecedented levels of customization, making ceramics more adaptable for use in cutting-edge applications across a range of industries. This section provides a detailed discussion of these advanced manufacturing techniques and their implications for ceramic technology [8-10].

### **Additive Manufacturing (3D Printing)**

Additive manufacturing, commonly known as 3D printing, is a revolutionary technology that involves the layer-by-layer construction of three-dimensional objects from digital models [11-15]. In ceramics, 3D printing has drastically changed the way complex ceramic components are designed and produced. This technology offers several distinct advantages for ceramic manufacturing:

- (i) One of the major benefits of 3D printing is its ability to create intricate and complex shapes that would be difficult, if not impossible, to produce using traditional ceramic fabrication methods. For example, porous structures, interlocking designs, and multi-material components can be seamlessly manufactured using 3D printing.
- (ii) Traditional ceramic manufacturing often involves significant material wastage, particularly during machining or mold-based processes. In contrast, 3D printing is a material-efficient process that uses only the required amount of ceramic material, reducing waste and lowering costs.
- (iii) 3D printing allows for rapid prototyping and customization of ceramic parts. This is particularly useful for producing specialized components in industries like aerospace, electronics, and healthcare, where each part may need to meet specific design and functional requirements. Customization is also important in the production of bioceramics for implants, where the material must be tailored to fit the patient's anatomy.
- (iv) The ability to manufacture directly from digital files means that design iterations can be rapidly tested and improved. This drastically shortens the design-to-production cycle, enabling faster innovation and reducing lead times.
- (v) Although 3D-printed ceramic parts often require post-processing, such as sintering or glazing, the ability to print green (unfired) ceramics allows for the production of near-net-shape components. This reduces the need for extensive machining or finishing, saving both time and resources.

3D printing in ceramics is widely used in the production of dental and medical implants, complex heat exchangers, filters, and even artistic sculptures. The ability to print functional ceramic parts for high-temperature and wear-resistant applications has opened

new possibilities in energy, aerospace, and industrial manufacturing sectors [16-20].

### **Precision Casting**

Precision casting, is another advanced technique that has significantly impacted the ceramic industry [21]. It involves creating a ceramic mold around a wax model, which is then melted away, leaving a cavity into which molten ceramic material can be poured. Precision casting offers several advantages for producing high-quality ceramic components:

- (i) One of the key strengths of precision casting is its ability to produce ceramic components with exceptional dimensional accuracy and fine detail. This makes it particularly useful for creating parts that require tight tolerances, such as turbine blades, intricate moldings, and industrial components.
- (ii) Ceramic parts produced via precision casting often have very smooth surface finishes, which minimizes the need for additional machining or finishing processes. This is especially advantageous in applications where surface quality is critical, such as in medical implants or precision tools.
- (iii) Precision casting is compatible with a wide range of ceramic materials, including high-performance ceramics like alumina, zirconia, and silicon carbide. This versatility allows manufacturers to tailor the properties of the final product to specific application requirements, such as high temperature resistance or biocompatibility.
- (iv) While precision casting is a labor-intensive process, it becomes cost-efficient for small-to-medium production runs where other methods, such as pressing or machining, would be prohibitively expensive. It is also ideal for producing ceramic parts that are too complex or delicate for traditional machining.

Precision casting is widely used in industries such as aerospace, automotive, and medical fields. High-performance ceramic components used in gas turbines, engine parts, and dental prosthetics are commonly produced using this technique due to its precision and reliability.

### **Automated Production Processes**

Automation in ceramic manufacturing has become increasingly important as industries demand higher production volumes, tighter quality control, and greater cost efficiency. Automated production processes in ceramics include the use of robotics, computer-controlled kilns, and automated assembly lines, which offer the following advantages:

- (i) Automation reduces the time required for repetitive tasks, such as material handling, mold making, and part assembly. Robotic arms can be employed to handle delicate ceramic components, minimizing the risk of human error and increasing production speed.
- (ii) Automated systems provide higher levels of

consistency in the production process, ensuring that each ceramic part meets strict quality standards. Sensors and monitoring systems integrated into automated lines can detect defects early in the manufacturing process, reducing waste and improving overall product quality.

- (iii) By minimizing the need for manual labor, automation can significantly reduce production costs. This is especially beneficial in large-scale manufacturing environments where high throughput is required.
- (iv) Advanced automation technologies, such as computer-controlled kilns, allow for precise temperature control during firing, optimizing energy use. This not only reduces production costs but also helps manufacturers meet environmental regulations regarding energy consumption.
- (v) Automation has evolved to allow for some degree of customization even in mass production settings. For example, automated assembly lines can be reconfigured to produce different product variants without requiring a complete overhaul of the production setup. This flexibility is particularly useful in industries where product specifications may change frequently.

Automated production processes are used in the mass production of ceramic tiles, sanitary ware, tableware, and technical ceramics. In industries such as electronics and telecommunications, automated processes are essential for the large-scale production of ceramic capacitors, substrates, and insulators. The integration of these advanced manufacturing techniques has created a synergy that is driving further innovation in ceramic technology. For example, 3D printing can be combined with automated processes to enable high-speed, large-scale production of custom ceramic components. Precision casting can benefit from automation in terms of mold handling and post-processing, increasing efficiency without compromising the quality of complex ceramic parts.

### Technology Clustering

In recent years, the convergence of nanotechnology and ceramics has opened new frontiers in material science, resulting in a significant surge in patents related to nanoceramics, particularly in the fields of electronics and biomedical applications. This upward trend in patent activity highlights the transformative potential of nanoceramic materials, which offer remarkable properties such as enhanced strength, improved thermal stability, and superior biocompatibility. The increased interest in nanoceramics for advanced applications is reflective of the growing demand for materials that can meet the stringent requirements of cutting-edge technologies. This discussion explores the key trends and innovations in nanoceramics, the driving factors behind the surge in patents, and the impact of these materials on electronics

and biomedical fields.

Nanotechnology involves the manipulation and control of materials at the nanometer scale, where unique physical, chemical, and mechanical properties emerge. Ceramics, long prized for their hardness, heat resistance, and electrical insulation capabilities, have been greatly enhanced through the incorporation of nanotechnology. Nanoceramics are ceramics that incorporate nanoscale particles or structures, which impart superior properties compared to their bulk counterparts.

This rise of nanotechnology in ceramics is driven by the following factors:

- (i) Nanoceramics exhibit dramatically different behaviors at the nanoscale due to the high surface area-to-volume ratio and quantum effects. For instance, the mechanical strength, toughness, and thermal stability of ceramics are significantly improved when processed at the nanometer scale.
- (ii) Industries such as electronics and biomedicine have stringent requirements for materials that offer high performance in extreme environments. Nanoceramics can fulfill these needs by providing advanced functionalities such as electrical conductivity, biocompatibility, or enhanced structural properties.
- (iii) As industries increasingly rely on nanoceramics for innovations, the number of patents related to these materials has surged. Companies and research institutions are actively filing patents to secure intellectual property in this rapidly growing field.

### Nanoceramics in Electronics: Patents and Applications

The electronics industry has been at the forefront of patent activity related to nanoceramics, with innovations aimed at addressing challenges in miniaturization, heat dissipation, and performance enhancement.

#### Dielectric Properties:

Nanoceramics are widely used in the production of capacitors, varistors, and other electronic components due to their superior dielectric properties. Patent filings in this area focus on the development of nanoceramic materials that improve energy storage capacity, reduce dielectric losses, and enhance miniaturization. For instance, barium titanate ( $\text{BaTiO}_3$ ), a commonly used dielectric material, exhibits significantly enhanced permittivity when processed at the nanoscale. This enables the production of more efficient and compact multilayer ceramic capacitors (MLCCs), which are crucial components in electronic devices.

#### Thermal Management:

As electronic devices become smaller and more powerful, managing heat dissipation has become a critical challenge. Nanoceramics with enhanced thermal conductivity are increasingly being patented for use in electronic packaging, substrates, and heat sinks. These materials improve heat transfer and prevent overheating



in high-performance devices such as smartphones, laptops, and power electronics.

#### **Magnetic and Optical Nanoceramics:**

The integration of nanoceramics into magnetic and optical components has led to innovations in data storage and photonic devices. Patents in this area focus on the use of ferrite nanoceramics in magnetic sensors and cores, as well as optical nanoceramics in lasers, light-emitting diodes (LEDs), and fiber optics. The ability to control magnetic and optical properties at the nanoscale has enabled higher data processing speeds and greater energy efficiency in modern electronics.

#### **Nanoceramics in Biomedical Applications: Patents and Innovations**

In the biomedical field, the use of nanoceramics has seen exponential growth due to their biocompatibility, bioactivity, and mechanical strength. The unique properties of nanoceramics at the nanoscale make them highly suitable for use in implants, drug delivery systems, and regenerative medicine. This has led to a surge in patent activity in biomedical nanoceramics.

**Biocompatibility and Implants:** One of the most significant areas of patent filings in nanoceramics involves their use in biomedical implants. Nanoceramics such as hydroxyapatite (HA) and zirconia ( $ZrO_2$ ) are favored for bone and dental implants due to their excellent biocompatibility, wear resistance, and mechanical strength. Patents in this field often focus on surface modifications at the nanoscale that improve the integration of the implant with surrounding biological tissues, promoting faster healing and reducing the risk of rejection.

**Drug Delivery Systems:** Nanoceramics are also being patented for use in drug delivery systems, where their controlled release properties are highly advantageous. Nanoporous ceramic materials can be engineered to release therapeutic agents in a sustained manner, improving drug efficacy and reducing side effects. For example, nanoceramic particles of silica or alumina have been explored as carriers for anticancer drugs, where they provide targeted delivery to cancerous tissues while minimizing damage to healthy cells.

**Tissue Engineering:** In tissue engineering, nanoceramics are used to create scaffolds that support the growth of new tissues. Calcium phosphate-based nanoceramics, for instance, are commonly employed in bone regeneration due to their bioactivity and ability to mimic the mineral composition of natural bone. Patents in this area focus on the development of nanoceramic scaffolds that promote cell adhesion, proliferation, and differentiation, paving the way for the regeneration of bone, cartilage, and other tissues.

**Antibacterial Properties:** Another exciting area of nanoceramic innovation involves their use in antimicrobial coatings for medical devices. Nanoceramics like titanium dioxide ( $TiO_2$ ) and silver-doped ceramics exhibit strong antibacterial properties, making them ideal for coating

surfaces that are prone to bacterial contamination, such as surgical instruments, catheters, and wound dressings. Patents related to nanoceramic antibacterial coatings have gained momentum as the demand for infection control in healthcare settings increases.

#### **Geographic Distribution of Patents**

The patent analysis highlights that the majority of ceramic-related patents originate from Asia, with Japan, China, and South Korea leading the innovation race. This reflects the dominance of these countries in the production and technological advancement of ceramics, particularly in electronics and industrial applications. Europe and the United States also contribute significantly, especially in high-tech sectors like medical ceramics and aerospace.

The top innovators in ceramic technology include both corporations and research institutions. Companies such as Kyocera, Saint-Gobain, and Corning are identified as leading patent holders, particularly in the fields of electronic ceramics and advanced manufacturing methods. Research institutions and universities, especially in Asia and Europe, are also contributing heavily to ceramic technology innovations, often focusing on nanotechnology and biomedical applications.

#### **Conclusion**

The patent analysis conducted in this study reveals significant innovation trends in ceramic technology, driven by advancements in materials, manufacturing techniques, and applications in emerging fields. Key trends such as the rise of nanoceramics, sustainable ceramics, and the integration of ceramics in electronic and biomedical technologies highlight the industry's dynamic evolution. As the demand for advanced materials continues to grow, the ceramic industry is well-positioned to play a pivotal role in addressing global challenges in sustainability, healthcare, and energy. This study provides a foundation for future research and development efforts in ceramic technology, offering valuable insights for industry stakeholders and policymakers alike. The surge in patents related to nanotechnology in ceramics, particularly in the fields of electronics and biomedical applications, reflects the enormous potential of nanoceramics in transforming industries. With their enhanced mechanical, thermal, and biocompatible properties, nanoceramics are unlocking new possibilities for innovation and commercialization. As research continues to advance, nanoceramics are set to play a pivotal role in the development of next-generation technologies across diverse sectors. Advanced manufacturing techniques such as additive manufacturing, precision casting, and automation have revolutionized ceramic production, enabling higher levels of precision, efficiency, and customization. These techniques have expanded the range of applications for ceramic materials, from traditional uses in construction and art to high-tech applications in aerospace, healthcare,

and electronics. As the ceramic industry continues to evolve, the adoption and further development of these manufacturing technologies will be key to maintaining competitiveness and driving innovation across the sector.

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