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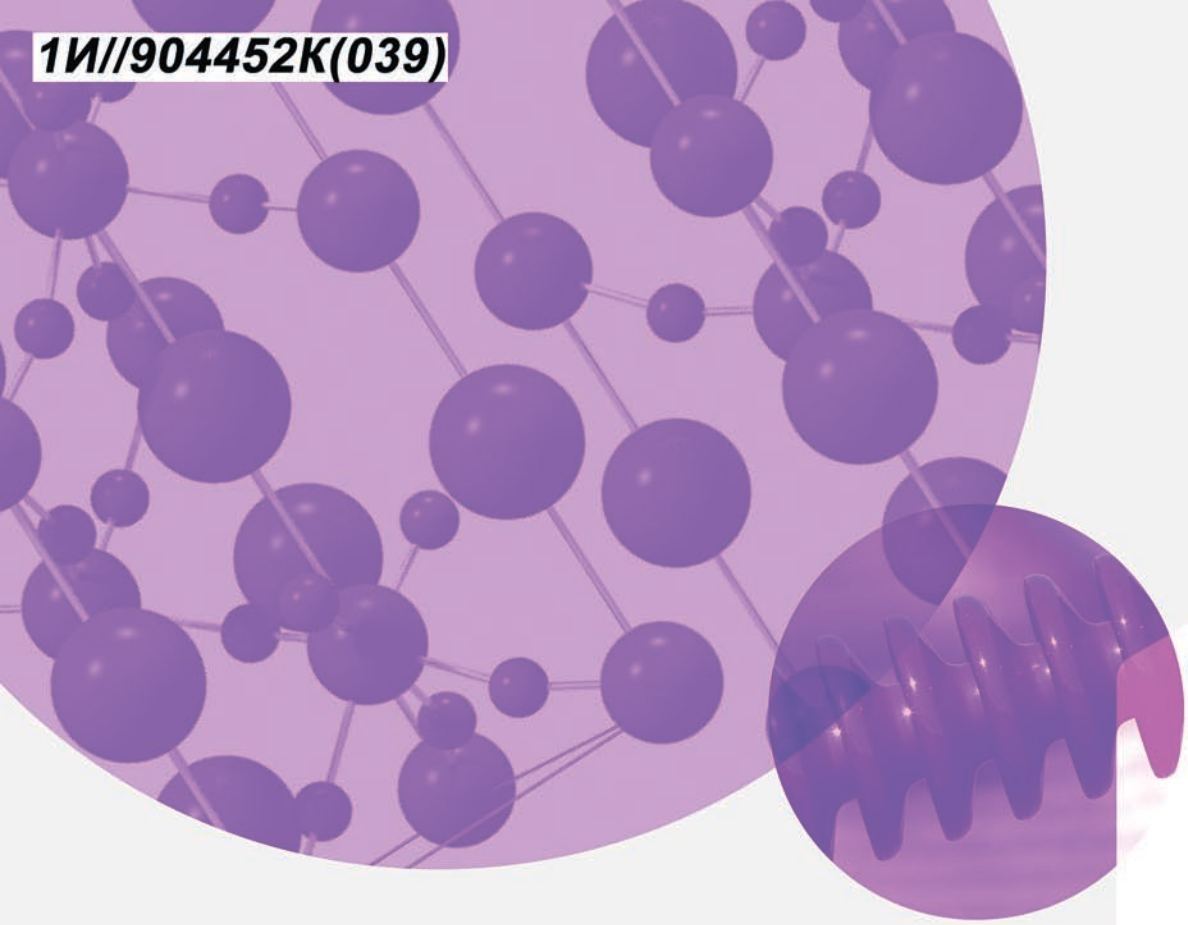

Patent Landscape Report

Production of titanium and titanium dioxide from ilmenite and related applications

WIPO

Contents

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Key findings

Titanium is a metal with high industrial and commercial interest. It is used in many applications in the form of dioxide, elementary metal or in alloys. Titanium is mainly extracted from ilmenite ore (82 percent), other sources being slags (13 percent) and rutile ore (5 percent). About 94 percent of the world's titanium is used to produce titanium dioxide, with the remaining 6 percent being used for titanium metal and alloys. China is the largest producer of titanium dioxide and titanium metal, followed by the United States of America (US) for titanium dioxide and Japan for titanium metal. This report provides a landscape of patenting activity relating to the production of titanium from ilmenite from 2002 to 2022, along with a section on patenting activity for selected industrial applications of titanium and titanium dioxide.

Patenting activity related to titanium dioxide production from ilmenite is rapidly increasing

Between 2002 and 2022, there have been 459 patent families that describe the production of titanium dioxide from ilmenite, and this number is growing rapidly. The majority of these patents describe pre-treatment processes, such as using smelting and magnetic separation to increase titanium concentration in low-grade ores, leading to titanium concentrates or slags. Other patents describe processes to obtain titanium dioxide, either by a direct hydrometallurgical process or through two industrially exploited processes, the sulfate process and the chloride process. Acid leaching might be used either as a pre-treatment or as part of a hydrometallurgical process to directly obtain titanium dioxide or synthetic rutile (>90 percent titanium dioxide, TiO_2). The sulfate process represents 40 percent of the world's titanium dioxide production and is protected in 23 percent of patent families. The chloride process is only mentioned in 8 percent of patent families, although it provides 60 percent of the worldwide industrial production of titanium dioxide. Given the findings from this patent landscape report, we can expect to see industrial chloride process use progressively decrease within the next few years and an increasing use of direct hydrometallurgical processes, which require fewer steps and are more convenient.

Key contributors to patents on the production of titanium dioxide are companies from China, Australia and the United States, reflecting the major contribution of these countries to industrial production. Chinese companies Pangang and Lomon Billions Groups are the main contributors and hold diversified patent portfolios covering both pre-treatment and the processes leading to a final product.

Patenting activity related to titanium metal production from ilmenite remains stable

Between 2002 and 2022, there have been 92 patent families that describe the production of titanium metal from ilmenite, and this number has remained quite steady. These patents describe the production of titanium metal starting from mineral ores, such as ilmenite, and from titanium dioxide (TiO_2) and titanium tetrachloride ($TiCl_4$), a chemical obtained as an intermediate in the chloride process. The starting materials are purified if needed, and then converted to titanium metal by a chemical reduction process using a reducing agent. Processes mainly differ in regard to the reducing agent used to transform the starting material into titanium metal: magnesium is the most frequently cited reducing agent and the most exploited in industrial production.

Key players in the field are Japanese companies, in particular Toho Titanium and Osaka Titanium Technologies, both focusing on reduction using magnesium. Pangang also contributes to titanium metal production and holds patents describing reduction by molten salt electrolysis.

As the patent dynamics are slow in this field and most industrial players describe the standard industrial process, we do not expect a big shift from this process within the next few years. The one emerging technology seems to be molten salt electrolysis developed by Pangang.

Titanium dioxide and titanium metal are used in a wide range of industrial applications

Patents on industrial applications of titanium dioxide and titanium from 2012 to 2022 were analyzed, focusing on six technological domains: ceramics, electrodes for batteries, medical technology, cosmetics, coatings and water treatment.

- **2,027 patent families described the increasing use of titanium dioxide and titanium composites in ceramics.** These materials are used as insulators in electronics, as well as for consumer goods (oven coatings), construction and decoration (tiles). Several leading industrial actors are among the top players, showing the maturity of this technology and its extended industrial use. Among the top industrial players, three are multinational corporations and world leaders in electronic components and devices: TDK, LG and Samsung.
- **1,874 patent families protected the use of titanium dioxide in electrodes and this number is growing rapidly, in part because of the development of electric cars.** Patents mainly focus on the use of titanium-based compounds as cathodes in lithium-based secondary batteries for electronics or automobiles. The presence of several big companies among the top actors shows the maturity of this technology and its broad industrial application. Among the top players, several leading multinational companies of the electronics and automobile industries are present: LG, Samsung, Toshiba, Toyota and Nissan.
- **1,182 patent families cited the use of titanium metal and alloys in medical technology, owing to the high strength-to-weight ratio and chemical stability of titanium, and the number is increasing rapidly.** Implantable products such as bone prostheses, cortical plates, stents and clamps are the most frequently described applications. Some patents also describe coatings for such implantable products and non-implantable surgical devices (guides, robots). Chinese companies and universities dominate this application field, with the Shanghai Jiao Tong University School of Medicine being the top contributor.
- **953 patent families protected cosmetic compositions containing titanium dioxide, mainly used for its opacity and high covering power, as well as an ultraviolet (UV) filter.** Patents cover products for hair coloring/dressing, sunscreen, toothpaste, skin whitening and make-up for skin or lips. The very large presence of big companies among the top actors reflects the high maturity of this technology. French multinational company L'Oréal is the top player with 53 active patents and is followed by several Japanese companies, such as Shiseido and Kao.
- **908 patent families described the use of titanium dioxide and composites in coatings.** This field is dominated by Chinese academic institutions and companies. Konfoong Materials International specializes in coating materials for semiconductors, Zhaoqing Hongwang Metal Industry is a steel manufacturer and Guangzhou UV Technology Material is another coatings manufacturer for glass, photovoltaics and decorative products.
- **719 patent families protected the use of titanium dioxide in water treatment.** This technology is rapidly emerging and expected to grow further within the next few years. Patents describe processes for water treatment, such as electrochemical processes, where titanium dioxide or titanium composites are used as electrodes, or purification by UV irradiation, where titanium dioxide is used as a photocatalyst. Other patents describe a purification technique based on the precipitation of impurities, where titanium tetrachloride is used as a coagulant. Key players are mainly Chinese universities with the exception of China Petroleum Chemical. The lack of industrial contributors reflects the low maturity of this technology and its growth potential.

Context and introduction

Introduction

Titanium extraction from mineral ores

Titanium is the ninth most abundant element on Earth and represents about 0.6 percent of the Earth's crust (Ngugen and Lee, 2019). It is used in several applications, mainly in the form of titanium dioxide, but also as titanium metal, or in alloys. Titanium dioxide is present worldwide in coastal deposits of heavy-mineral sands, which are sources of heavy industrial minerals, such as ilmenite, rutile and leucoxene.

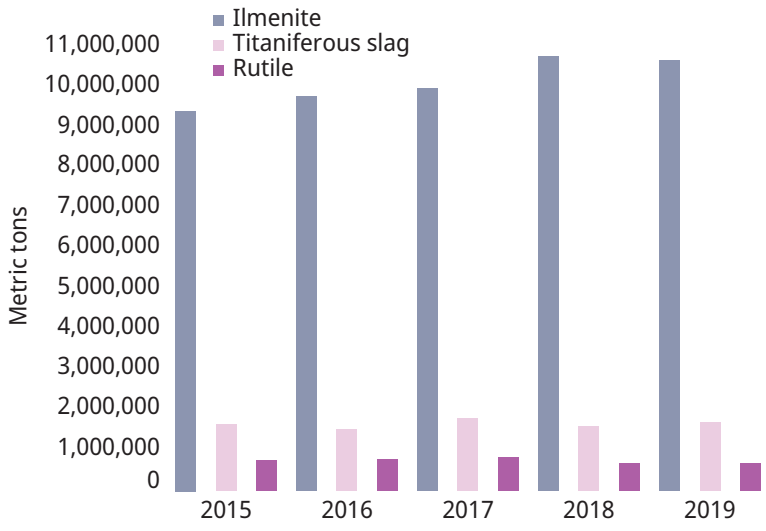
This report provides a landscape of the patent activity related to the process of extracting titanium dioxide or titanium metal from ilmenite ore. In addition, a section on the industrial applications of titanium dioxide and titanium metal is included, focusing on selected applications, such as ceramics, electrodes for batteries, medical technology, cosmetics, coatings and water treatment.

The mineral ilmenite is mainly composed of iron and titanium oxide having an ideal chemical formula $FeTiO_3$ and a stoichiometric content of 53 percent titanium dioxide (TiO_2), although the real TiO_2 content varies between 40 and 65 percent (Van Gosen and Ellefsen, 2018; Ngugen and Lee, 2019). Indeed, weathering can increase the TiO_2 content in titaniferous ores by leaching the iron. Natural rutile contains around 95 percent TiO_2, while leucoxene comprises a mixture of $FeTiO_3$ and TiO_2 with a total TiO_2 content over 65 percent (Ngugen and Lee, 2019).

Ilmenite is commonly processed to obtain a titanium concentrate, which is called "synthetic rutile" if it contains more than 90 percent TiO_2, or more generally "titaniferous slags" if it has a lower TiO_2 content.

More than 80 percent of the estimated global production of titanium concentrate is obtained from the processing of ilmenite, while 13 percent is obtained from titaniferous slags and 5 percent from rutile (Figure 1).

Figure 1. **Estimated world production of titanium concentrate by mineral source in metric tons, 2015–2019.**
Titanium concentrate is mainly obtained from processing of ilmenite mineral, followed by titaniferous slags and natural rutile.



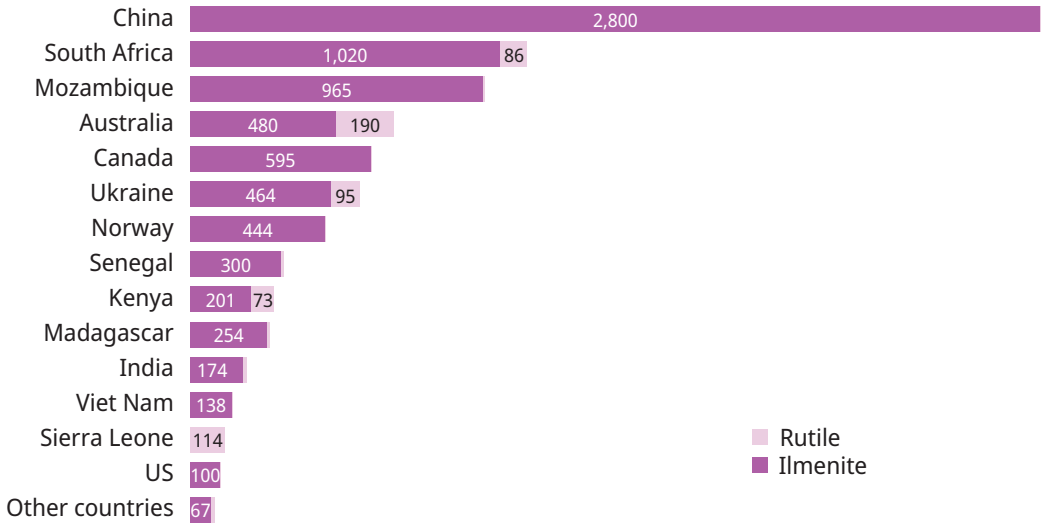
Source: based on data from USGS (n.d.).

Titanium mining and world production

China has by far the highest titanium mining activity (Figure 2). About 35 percent of the world's ilmenite is mined in China, representing 33 percent of total titanium mineral mining (including ilmenite and rutile). South Africa and Mozambique are also important contributors, representing 13 percent and 12 percent of worldwide ilmenite mining, respectively. Australia represents 6 percent of the total ilmenite mining and 31 percent of rutile mining.

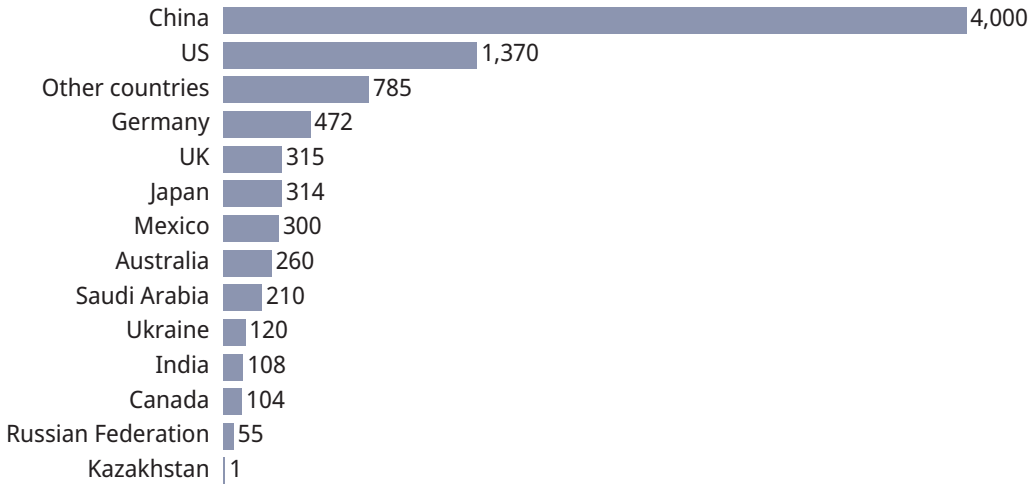
China is the biggest producer of titanium dioxide, followed by the United States and Germany (Figure 3). China is also the leader in the production of titanium metal, but Japan, the Russian Federation and Kazakhstan have emerged as important contributors to this field (Figure 4).

Figure 2. **Worldwide mining of the titanium-containing minerals ilmenite and rutile in thousand tonnes of TiO_2 equivalent by country, 2020.**
China, South Africa and Mozambique are the biggest contributors to ilmenite mining, while Australia, Sierra Leone and Ukraine are the biggest contributors to rutile mining.



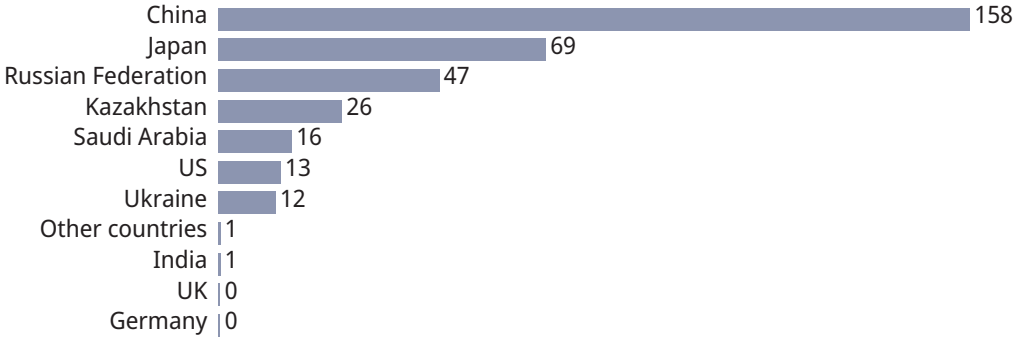
Source: based on data from USGS (n.d.).

Figure 3. **Production capacity (in thousand tonnes) of titanium dioxide by country, 2020.**
China has the largest production capacity for titanium dioxide, followed by the United States.



Source: based on data from USGS (n.d.).

Figure 4. **Production capacity of titanium metal by country, 2020.**
The main producers of titanium metal are China, Japan and the Russian Federation.

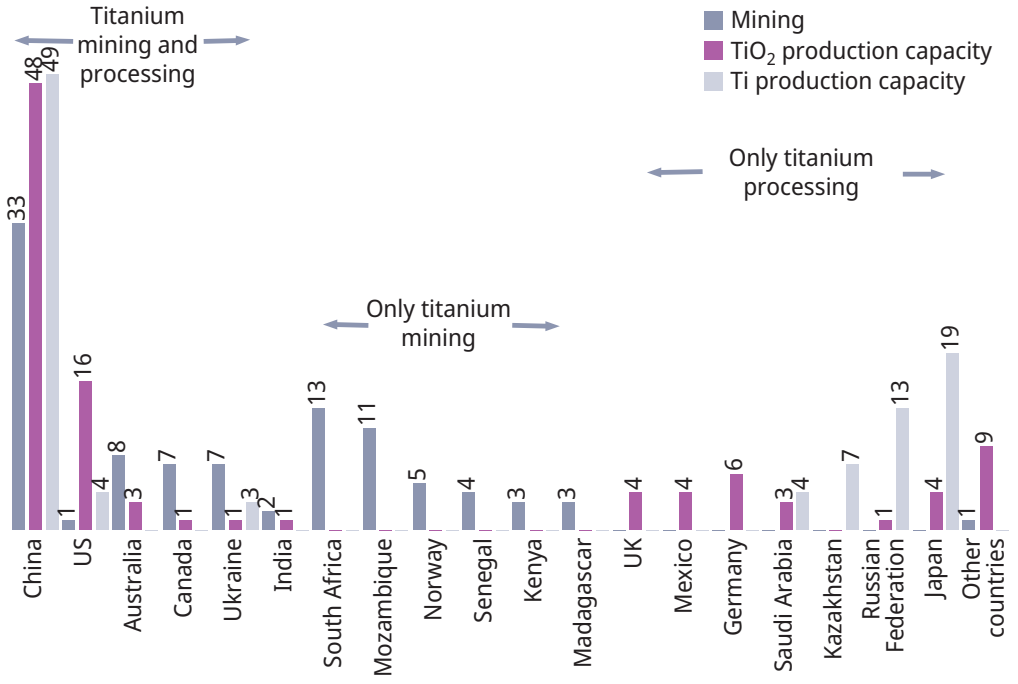


Source: based on data from USGS (n.d.).

Figure 5 compares the contribution of the different countries to the mining of titanium-containing ores and production of titanium dioxide and titanium metal:

- China leads titanium mining and processing, representing 33 percent of worldwide titanium mining and almost 50 percent of total production of titanium and titanium dioxide.
- The United States, Australia, Canada, Ukraine and India are active in both titanium mining and processing.
- South Africa, Mozambique, Norway, Senegal, Kenya and Madagascar are only sources of ores and are not involved in titanium processing.
- Japan, the Russian Federation, Kazakhstan, Saudi Arabia, Germany, Mexico and the United Kingdom (UK) are not involved in mining the natural ores, but are important contributors to the processing of ores or slags and the production of titanium dioxide and/or titanium metal.

Figure 5. **Percentage contribution by country to the mining of titanium-containing ores, TiO_2 production and Ti production (estimated based on production capacity), 2020.**
Some countries contribute both to the mining and processing of titanium (China is the leader). Other countries, mainly in Africa, contribute only to mining, while several Asian and European countries contribute only to processing.



Source: based on data from USGS (n.d.).

This report provides a patent landscape of the processes used to extract titanium dioxide and titanium metal from ilmenite ores. The landscape has worldwide coverage for the years 2002–2022. Patents on extraction of titanium dioxide and titanium metal are categorized according to the starting raw materials used, the type of process described and the final product.

In addition, a section is dedicated to patents describing industrial applications of titanium and titanium-based compounds. Again, this landscape has worldwide coverage and is restricted to active patents from 2012 to 2022. Patent activity was analyzed focusing on six technological fields corresponding to high-tech applications with increasing activity since 2012: ceramics, electrodes for batteries, medical technology, cosmetics, coatings and water treatment.