Technology of ion implantation of structural materials (patent life-cycle analysis)

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Abstract. The article presents a patent analysis of the life cycle of ion implantation technologies for structural materials. S-curve. In the total volume of patent documents, the Russian Federation ranks first in the number of patent documents (125). The dynamics of published patent documents in the field of technology has proved that in 2014 the number will not be reached.

The technology of ion implantation remains one of the most productive sectors in the world despite the fact that it is also the most difficult. The ion beam treatment can be used to improve corrosion resistance, harden the surfaces, reduce wear, and improve the properties of materials. The formation of the structure during ion implantation occurs under the influence of the processes of ion sputtering, ion-stimulated migration of atoms in the surface layers and depends on the physicochemical and thermodynamic properties of the implanted ions and the irradiated materials. The implantation process itself, its modes (radiation dose, time, accelerating voltage, etc.) also have an important significance on the structure formation. [1-3].

In connection with the interest in the development of technologies for processing structural materials based on ion implantation, analysis of patent information was conducted with a life cycle assessment. In accordance with the purpose of the study, applications and patents were analyzed from 1986 to 2019. During the search, official publications of security documents (patents and certificates), as well as national and international patent applications of leading countries of the world were taken into account. Of the more than 270 thousand documents reviewed, 322 closest to the technology of ion implantation of structural materials were selected for further analysis.

Patent databases (DBs) of leading countries (USA, Japan, Germany, China, RF) and sites of the Eurasian Patent Office (EAPO), European Patent Organization (EPO-Espacenet) and World Intellectual Property Organization (WIPO) - PATENTSCOPE.

As you know, using data on the number of patent applications and patents received, you can get an idea of the stages of technology development. This process consists of several stages, starting with intellectual activity and ending with entering the market [4]. At the same time, the S-curve is used to assess the life cycle (Figure 1), which reflects various stages: the “emergence” stage in which the new technology has almost no competitive influence and is poorly integrated into products and processes; a growth stage in which topics of technology diffusion are accelerated, while integration into new
products or processes is still small; a stage of maturity in which a number of common technologies acquire the status of key and are strained into products or processes; the “saturation” stage in which the technology becomes basic and can be replaced with a new [5].

![Figure 1. The S-curve concept of technology life cycle [5].](image)

The analysis of the identified patent documents allowed us to identify the main indices of the International Patent Classification (IPC), of which the leading one is С23С / 14 - the coating of a metallic material, coating other materials with a metallic material; surface treatment of the metal material by diffusion into the surface by chemical transformation or substitution; methods of coating by vacuum evaporation, sputtering, ion implantation, or chemical vapor deposition (Table 1).

| IPC       | Description IPC                                                                 | Repetition rate |
|-----------|---------------------------------------------------------------------------------|-----------------|
| C23C 14/48| Coating by vacuum evaporation, metal sputtering or ion implantation of the material forming the coating - ion implantation | 89              |
| C23C 14/06| Coating by vacuum evaporation, metal sputtering or ion implantation of the material forming the coating - characterized by the covering material | 12              |
| C23C 14/34| Coating by vacuum evaporation, metal sputtering or ionic implantation of the material forming the coating - sputtering | 6               |
| C23C 14/02| Coating by vacuum evaporation, metal sputtering or ion implantation of the material forming the coating - pretreatment of the material to be coated | 4               |
| C23C 14/50| Coating by vacuum evaporation, metal sputtering or ion implantation of the material forming the coating - substrate holders | 3               |
| C23C 14/04| Coating by vacuum evaporation, metal sputtering or ion implantation of the material forming the coating - coating on a selected surface area, for example using masks | 3               |

An important indicator is the date of publication of the patent document, indicating the achieved technical level and the relevance of the proposed technology (Figure 2). As can be seen from Figure 2, two peaks are clearly visible, separated by a distance, which indicates the growing attention of researchers, inventors and companies to ion implantation technologies. In the first period, when the technology has not yet received appreciable recognition, only two patents were registered for it in 1986 and 1987. The second period began with seven patents filed in 1990, then activity continued until
2013. The next “maturity” period began in 2014 and lasts until the present time, i.e. the largest number of patents registered during one year is 26 in 2014, becoming an illustration of the revolutionary changes in the technology under consideration and belongs to the “saturation” stage.

![Figure 2. Dynamics of publication of patent documents in the field of ion implantation technology.](image)

Such rapid growth can be explained by developments and research in the field of nanocrystalline materials. The inflection points of the S-curve, judging by the available data, is between 2003 and 2009. Then the growth increased and continued to grow until 2016.

Currently, there is a smooth decline. Despite this, it should be noted that the dynamics of patenting in the field of ion implantation is currently preserved, which indicates the interest and relevance of the technology.

For the study of world-class scientific research in the study area, an analysis of patent activity in various countries of the world was carried out, on the basis of which the main development trends were identified (Figure 3).

It was revealed that the leading positions in the number of patent documents are occupied by Russia (125) and China (72), the USA is in the 3rd place (42).

![Figure 3. The number of patent documents by country on the technology of ion implantation of structural materials (1986-2019).](image)
The number of international applications (PCT) and patent documents (European Patent Office) in the total amount of analysed patent documents was 14, of which the main applicants and patent holders are legal entities. The development of the technology sector of such developments at the international level is most likely connected with commercial companies that have the appropriate resources in their material support and are ready to implement the claimed technology not only in their territory or issue licenses for their production, but also abroad [6].

The main applicants in the field of surface modification of titanium alloys are foreign legal entities (Figure 4).

In the Russian Federation, the main applicants and patent owner are universities and research institutes, in particular, the largest number of patents in the studied area was found in the Research Institute of Nuclear Physics at the Tomsk Polytechnic University (NII NF TPU), Ufa State Aviation Technical University, and Moscow Polytechnic University.

**Figure 4.** Dynamics of patent documents on legal entities in the field of surface modification of titanium alloys by high-energy energy flows.

**Conclusions**

Our research is based on a positive analysis of patent activity, a positive S-curve model that describes the trajectory of technological development as applied to ion implantation technologies. Patent applications, attitudes to it, were distributed over three periods. At the stage of inception and the beginning of the introduction of technology (1986–1987). Patent activity grew slowly. A number of large-scale events of 1990–2013, for example, active research in the field of nanocrystalline materials, markedly stimulated the growth of patenting in this direction. Despite fluctuations in patent activity, the overall rate of growth remained constant. Analysis of trends and life cycle suggests that ion implantation technology is in the period of maturity, the saturation stage is expected to be reached in 2025–2040.

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