

Evaluation Method for Technology Readiness Assessment in High-purity Metal Target

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Abstract: Technology readiness level is an assessment tool for technology risk control, widely used in large-scale complex engineering such as military and aerospace industries. High purity metal targets are one of the key materials required for production in fields such as semiconductors, flat panel displays, and solar cells. The technology and process are very complex, which determines the level of technological maturity and will have a significant impact on downstream applications. This article combines the needs of downstream users and establishes a technology maturity evaluation model for high-purity metal targets with "parameters-indicators-data" as the core. It develops a technology maturity evaluation method suitable for high-purity metal targets and uses high-purity cobalt targets as an example for evaluation and application practice. It diagnoses the problems existing in the industrialization process, proposes improvement suggestions, and helps target production enterprises continuously improve and enhance.

Key words: technology readiness level; high-purity metal target; evaluation method

Technology Readiness Level (TRL), also known as Technology Readiness, refers to the degree to which a technology meets expected application and industrialization goals. As an evaluation tool for technology risk control, it is widely used in large-scale complex engineering such as military and aerospace industries[1]. High purity metal targets are one of the key materials required for production in fields such as semiconductors, flat panel displays, and solar cells. The technology and process are very complex, which determines the level of technological maturity and will have a significant impact on downstream applications. In recent years, China has invested heavily in the research and development of high-purity metal targets, producing a large number of research results. However, many of the so-called "achievements" that have been formed are not achievements in the true sense. It is difficult to have both progressiveness, practicality, maturity, commercial value and other aspects at the same time. They do not reach the maturity that can be transformed into production and cannot be applied to production. Therefore, it is of great significance to use technological maturity to guide technological innovation, quantify input-output, and reduce industrial risks.

1. Introduction to Technology Maturity Evaluation

Technology Readiness Assessment (TRA): Using technology maturity standards, a scientific and rigorous implementation procedure is used to evaluate the technical maturity of key technologies in a system or project[2]. The maturity of technology and its evaluation techniques were first proposed by the National Aeronautics and Space Administration (NASA) in 1989 and used as evaluation tools. They gradually matured in the 1990s and were widely used by the US Department of Defense (DOD) for defense procurement project management in the 21st century[3]. Subsequently, technology maturity assessment was gradually widely used by organizations such as the US Department of Energy (DOE), the Audit Office (GAO), the US Department of Homeland Security (DHS), and the European Space Agency (ESA).

In 2009, China released the "General Principles for Evaluation of Scientific and Technological Research Projects" (GB/T 22900-2009), which established evaluation indicators for technology

maturity based on basic research projects, applied research projects, and development research projects, and clarified the WBS decomposition based technology maturity evaluation method in this standard[4]. In 2019, China released the "Classification and Definition of Maturity Levels for New Materials Technology" (GB/T 37264-2018) [5]. This standard is compiled by authoritative standard organizations in the four major raw material fields of steel, non-ferrous metals, building materials, and petrochemicals, organized by the Raw Materials Department of the Ministry of Industry and Information Technology of China. The technical maturity is divided into nine levels: laboratory, engineering, and industrialization. The problems in the research and development/production process of new materials are analyzed from the perspective of industrialization, and the requirements for technical and process control indicators of materials are also gradually improved. The release of this standard has solved the problem of the lack of maturity standards for evaluating new material technology in China. In 2020, the State Administration for Market Regulation and the National Standardization Administration issued the "Classification and Definition of Maturity Levels of Target Materials Technology" (GB/T 39157-2020)[6], which defined the requirements for each level of target materials. In the field of aerospace and other fields, China has issued the "Guidelines for the Maturity Evaluation of Aerospace Engineering Technology" (GB/T 40518-2021) [7], which provides the specific process of technology maturity evaluation. The release of the above standards provides a guiding basis for the technical maturity evaluation of high-purity target materials.

2. Research ideas on technology maturity evaluation

This article combines the research and development, application research, standardization, and downstream user application verification requirements of high-purity metal targets, and establishes a technology maturity evaluation method for high-purity metal targets. The research approach adopted by this evaluation method is "from the whole to the parts, from the parts to the whole". Specifically, first, from the whole to the local, determine the scope of evaluation objects, determine the specific varieties of high-purity metal targets, perform Work Breakdown Structure (WBS), and identify critical technology elements (CTE); Refine the specific requirements based on key technical elements and form a nine level technical maturity evaluation rule. From local to overall, based on the parameters, indicators, and data requirements in the nine level technology maturity evaluation detailed rules document, the specific maturity level requirements of key technology elements are determined to achieve the evaluation of individual technology maturity of key technology elements. Finally, the evaluation results of individual technology maturity of key technology elements are integrated according to the "barrel law", Identify the key factors that constrain the technological maturity of the high-purity metal target, ultimately determine the technological maturity level of the high-purity metal target, and propose improvement suggestions to help material research and development units continuously improve, laying the foundation for the next step of conducting higher level technological maturity evaluation. The research approach is shown in Figure 1.

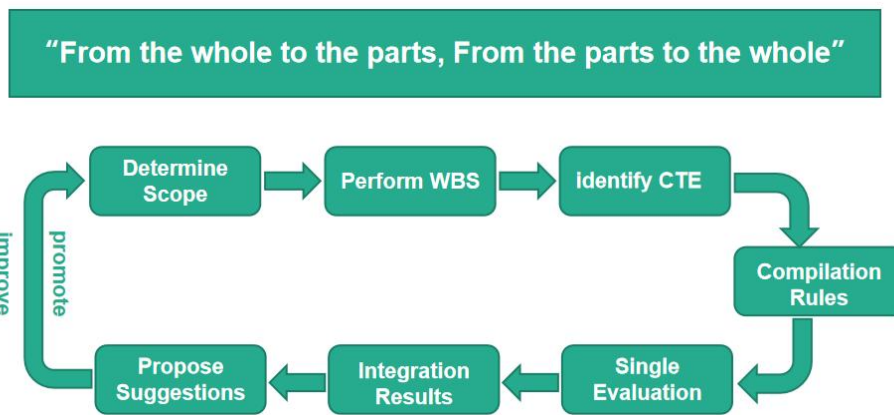


Figure 1 Research ideas on the maturity evaluation of high-purity metal target technology

3. Application Practice of Maturity Evaluation of High Purity Cobalt Target Technology

The high-purity metal target industry is a typical technology intensive industry based on metallurgical purification, plastic processing, heat treatment, and mechanical processing. High purity cobalt target material is one of the current hot research topics in high-purity metal target materials. It has obvious advantages in improving driving current, frequency response, and operating speed, replacing tungsten contact holes and copper interconnects, and improving chip conductivity. It has become an important conductive material for advanced processes, and is one of the key materials for preparing ultra large scale integrated circuit logic chips and DRAM storage chips. It can effectively reduce device impedance and power consumption. However, high-purity cobalt target materials require high purity. The manufacturing method is to first sinter high-purity cobalt powder into blocks, then obtain high-purity cobalt ingots through a high vacuum electron beam melting furnace. Then, the cobalt ingots are repeatedly subjected to plastic deformation and annealing to obtain cobalt target blanks with uniform grains and certain internal textures. Finally, the finished product is formed by welding and mechanical processing with the backing plate. This method has a long process flow and high requirements for production technology, machinery and equipment, process flow, and working environment, resulting in insufficient consistency and stability of target products, low yield rate, and high cost. Especially in key performance indicators such as magnetic permeability and welding rate, there is still a gap compared to similar products in developed countries.

In order to avoid significant technical risks during the industrialization stage, our project team collaborated with a high-purity cobalt target production unit to conduct a technology maturity evaluation during the R&D to engineering stage, helping the unit diagnose the technical risks in the R&D process and propose improvement suggestions. The overall process is as follows:

The first step is to determine the evaluation object as the high-purity cobalt target material for ultra large scale integrated circuits. The second step is to decompose the work structure. The process of the high-purity cobalt target material is divided into 9 system work breakdown structures (WBS), including "raw material preparation, melting, forging, rolling, heat treatment, welding, machining, testing, and packaging". The third step is to identify key technical elements. Five key technical elements (CTE), including raw material preparation, melting, rolling, welding, and testing, will be identified through expert evaluation and other methods. Step 4, prepare evaluation rules. Based on the specific requirements of the 5 CTE, concretize the definition requirements of GB/T 37264 and GB/T 39157 standards, quantify specific evaluation indicators, parameters, and data, and develop a nine level technical maturity evaluation rule as the basis for quantitative evaluation. Step 5, evaluate each of the 5 CTE one by one. Using the evaluation form method, evaluate from TRL1 level by level, compare the evaluation rules and the evaluation support materials provided by the

evaluated party, and organize the evaluation until there are any non compliant items. Step 5, integrate the evaluation results. Determine the technical maturity level of the high-purity cobalt target material based on the lowest technical maturity level of CTE. Finally, 10 improvement suggestions were proposed for the unit, including quality control, safety and environmental protection, production and operation, inspection and testing, to help the unit achieve comprehensive improvement.

The entire evaluation project process is divided into 3 stages and 9 steps. In the preparation stage, it mainly includes evaluation planning, preparation of self-evaluation reports, and review of self-evaluation report forms. In the implementation phase, it mainly includes evaluation plan arrangement, document review, and on-site inspection and evaluation. The evaluation decision stage mainly includes report approval, evaluation compliance, and certificate report issuance. With the strong cooperation of the evaluated unit, the entire evaluation was completed within 3 months, and the results were recognized by industry experts and downstream customers.

3.1 Determine the scope of evaluation objects

Technical maturity refers to the development status of technology relative to a specific system or project goal. Therefore, when evaluating the technical maturity of high-purity cobalt targets, it is necessary to clarify the application scenarios of the materials in order to cover the connotation of technical maturity. Finally, the evaluation object is determined to be high-purity cobalt targets for ultra large scale integrated circuits.

3.2 Carry out Work Structure Decomposition (WBS) and identify Key Technical Elements (CTE)

When evaluating the maturity of technology, the key step is to screen and determine CTE through the WBS of the task, evaluate each key technical element, and ultimately obtain the technical maturity of high-purity cobalt target materials. Therefore, CTE plays a decisive role in the technological maturity level of high-purity cobalt targets. The work breakdown structure refers to the process of breaking down project deliverables and work into smaller and more manageable components, which can be understood as the main process or link. Key technical elements refer to the technologies that must be relied on to complete the performance requirements and tasks set by the project within the specified time and cost range, and can be understood as key technical elements.

3.3 Develop detailed rules for evaluating the level nine technology maturity

Although national standards have defined the technical maturity of materials at various levels, standards are only a guiding document and can only achieve preliminary qualitative evaluation. For projects from different industries and backgrounds, the technology itself has its own unique characteristics, and the general TRL lacks specificity, resulting in inaccurate descriptions of the maturity of specific materials. Therefore, it is necessary to redefine (concretize) the TRL of high-purity cobalt target materials, and form more accurate, targeted, and applicable evaluation criteria that can reflect the technical characteristics of high-purity cobalt targets more accurately by quantifying the parameters, indicators, and data requirements of each project. The preparation of evaluation rules is not to overturn the general TRL definition, but to refine and reflect the characteristics, integrating the requirements for key technical elements into the rules, achieving specific evaluation methods, specifying verification environments and technical carriers, and step-by-step risk control, becoming the basis for evaluating key technical elements.

In the process of formulating evaluation rules, attention should be paid to systematically organizing the parameters, indicators, and data related to high-purity cobalt targets. Among them, parameters include material intrinsic parameters, application parameters, production process parameters, and industrialization parameters. The parameters are derived from existing standards and technical specifications, and are an important basis for evaluation. Indicators are the threshold

values for key parameters. Batch data is an important basis for consistency stability evaluation. System statistical analysis of data is an important support for downstream customer acceptance. Therefore, in formulating the nine level technical maturity evaluation rules, it is necessary to concretize and digitize the parameters, indicators, and data.

3.4 Single item maturity evaluation of key technical elements

The evaluation method based on checklists is to decompose the detailed connotations and indicators of each maturity level according to the definitions of different levels of TRL in the nine level technology maturity evaluation rules, form specific judgment criteria and criteria, and compile an evaluation form for each maturity level.

When using the checklist evaluation method for maturity evaluation, a step-by-step evaluation method from level one to level nine is usually adopted. Based on the description of the key technical elements of the evaluated object, compare the description requirements in the maturity level table to evaluate whether the key technical elements fully meet the conditions in the checklist. If they cannot meet the requirements, it indicates that the CTE can only reach the maturity level of that level, and ultimately determine the maturity position of the technology.

3.5 Integration of Technology Maturity Evaluation Results

After evaluating the TRL of each CTE, according to the "barrel law", the lowest level TRL of CTE is ultimately determined as the TRL of the high-purity cobalt target material. This CTE is also a key factor that restricts the technological maturity of the high-purity cobalt target material and a key bottleneck.

3.6 Improvement and enhancement of technology maturity evaluation

Determine the TRL level of the high-purity cobalt target material, trace back to the key technical elements that limit its technological maturity, analyze the existing problems, analyze the reasons, propose improvement suggestions, reduce research and development risks, help it improve to a higher level of technological maturity, and achieve continuous improvement in PDCA.

4. Summary

This article takes high-purity metal targets as the research object, draws on the practical experience of technology maturity evaluation at home and abroad, combines the production characteristics of high-purity metal targets with China's scientific and technological level and industrial foundation in this field, establishes a technology maturity evaluation method for high-purity metal targets, and conducts preliminary application practice. Empirical research on the evaluation of high-purity cobalt targets has shown that this evaluation method can scientifically and intuitively reflect the true technical level and industrialization stage level of high-purity metal targets, provide a more systematic reference for the next industrial decision-making, point out specific directions for the continuous improvement of technological maturity, and provide a reliable basis for objectively grasping and identifying technical and management risks, Has strong targeting and practicality.

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