PR-9P

Progress of the segmented mirror fabrication for the TMT

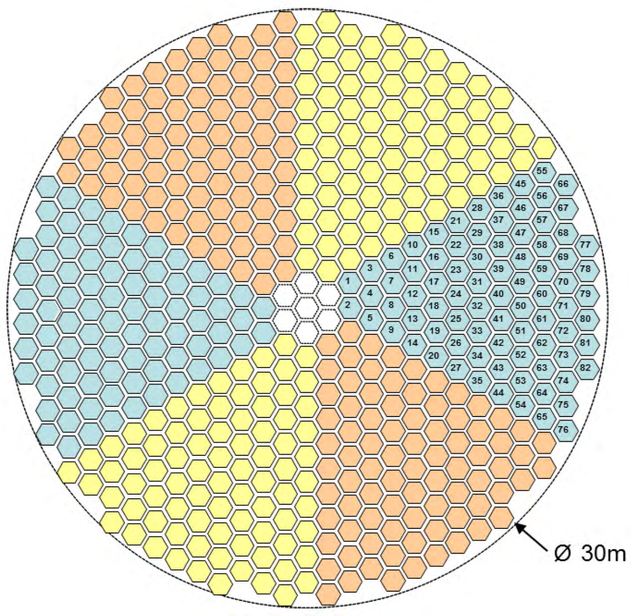
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Overview of the TMT Primary Mirror

The TMT primary mirror consists of 492 hexagonal segments, each 1.44 meters in diameter and 45 millimeters thick, arranged to form an effective diameter of 30 meters. The mirror surface is a hyperboloid with an approximate radius of curvature of 60 meters, meaning the primary mirror's focal length is 30 meters.

The 492 primary mirror segments are grouped into sets of six identical segments each, resulting in a total of 82 distinct segment types manufactured. Arranging these 82 differently shaped primary mirror segments creates a pattern resembling one slice of a pizza divided into six pieces.

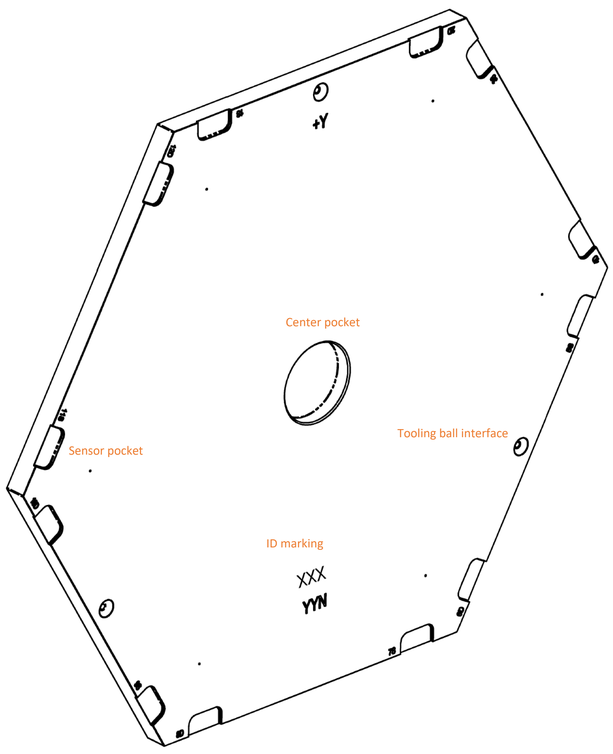
Additionally, seven identical primary mirror segments are manufactured for each segment type to serve as replacements during coating, bringing the total number of segments produced to 574.



Arrangement of TMT primary mirror segments

Advantages of Segmented Mirrors over a Single Mirror

The silver coating on the primary mirror's reflective surface degrades over time, reducing reflectivity. Therefore, after a certain period, the coating is removed and a new coating is applied. Once the primary mirror segment undergoing recoating is removed from the telescope, the replacement segment is immediately installed. This allows for recoating of the primary mirror segments without any downtime.



Back isometric view of a TMT mirror segment

Processing of Segment Mirrors

Each primary mirror segment incorporates: - Pockets housing sensors to measure position relative to adjacent segments - A pocket connecting the segment to the lateral support central diaphragm - Tooling ball interfaces for positioning the segment during mounting to the support structure - Symbols machined onto the surface to identify the mirror material.

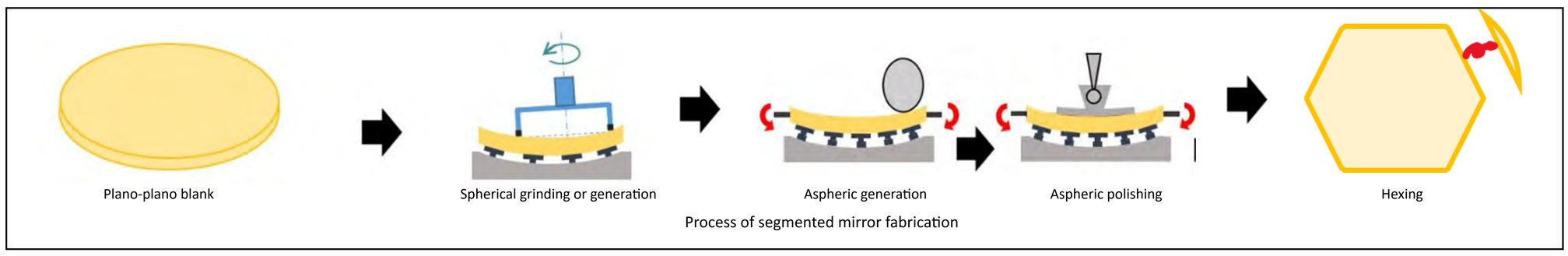
Material for TMT Primary Mirror Segments

The material chosen for the primary mirror segments is Clearceram-Z from OHARA INC. This ultra-low expansion glass-ceramic offers excellent mechanical properties and machinability, making it the optimal choice for the TMT primary mirror material.


TMT segment blanks made of Clearceram-Z by OHARA Inc. during the test fabrication in 2024. Out of five blanks manufactured from a block, three blanks had their central section hollowed out and used for measuring thermal expansion coefficients and residual stresses.

Manufacturing Process for the Primary Mirror Segments

The manufacturing process for the primary mirror segments is as follows. First, a cylindrical glass-ceramic block is produced in OHARA INC.'s dedicated Clearceram-Z melting furnace. This block is then sliced into five thin pieces. Next, the front and back surfaces of each thin disc are spherically ground. The front surface is then ground and polished into an aspherical shape, while the back surface is polished. Finally, the aforementioned features are machined onto the back surface, and the circular mirror blank is shaped into a hexagon to complete the mirror blank. The final machining of features and hexagonal shaping process is collectively referred to as hexing. After completion, the finished mirror blank is mounted on a segment support mechanism. The mirror's surface shape is refined via ion beam shaping before proceeding to the reflective coating process.



Process of segmented mirror fabrication

Progress in Primary Mirror Segment Manufacturing

All optical material for the primary mirror segments is manufactured by OHARA Inc. All subsequent spherical grinding or generation is performed by a Japanese processing contractor. Japan, the United States, and India share responsibility for the next process steps on the spherical ground mirror blanks.

To date, 356 glass blanks have been manufactured, with 341 undergoing spherical grinding. Of these, 185 were shipped to the United States and 20 to India. In the United States, 152 have completed aspheric polishing, while aspheric polishing is about to begin in India. Meanwhile, in Japan, 33 have completed aspheric polishing.

Activities toward resuming primary mirror segment material production

As construction of the TMT main structure has not progressed, the production of the primary mirror blanks has been suspended since the end of fiscal year 2019. However, anticipating a near-future resumption of manufacturing, the TMT project is preparing to restart blank production and spherical grinding or generation. The melting furnaces used to produce the blank have a finite lifespan. When a furnace is refurbished, it must first be verified that it can produce blank meeting TMT specifications before blank production can commence. For example, the thermal expansion of the blank must be below a specified threshold because it affects the shape accuracy of the mirror surface. Since the mirror surface shape is determined by all 492 primary mirror segments, the upper limit for the thermal expansion coefficient is required to be $0\pm40\times10^{-9}$/°C, representing the average thermal expansion coefficient of all primary mirror segments (The Composite Operation-Temperature CTE). For reference, the typical thermal expansion coefficient of Pyrex glass used in tableware is 32.5×10^{-7}/°C. Since the thermal expansion coefficient of the blank material depends not only on the material and manufacturing process but also on the performance of the melting furnace, prototype blank was actually produced in the refurbished melting furnace and its thermal expansion coefficient measured during 2023 to 2024. Regarding spherical grinding or generation, the equipment was relocated from the contractor's factory where processing was performed until fiscal year 2019 due to the suspension of TMT blank processing. The equipment must be returned to verify processing accuracy. This work is scheduled to be completed by March 2026.

Preparation Status for Hexing Study

Regarding hexing, prototyping using replicas of the primary mirror segments has only been performed in the United States to date; prototyping using actual mirror blank has not been conducted anywhere. In Japan, small 30cm square blank materials have been used to verify the precision of the processing machinery and to test-machine various features. By August 2026, we plan to complete machine maintenance and precision verification, followed by trial machining using a 30cm square blank material.

We are also investigating methods for shaping a circular mirror blank into a hexagonal form through trial machining. The initial plan was to gradually grind a circular mirror blank into a hexagon. However, this incremental removal would be extremely time-consuming. Furthermore, the shavings cannot be reused and become waste, incurring disposal costs. Other telescope projects use wire saws or band saws for cutting. The problem with this approach is that the machining equipment and the wire saw or band saw are separate machines, necessitating the transfer of the mirror blank from one machine to another for processing. While it's not impossible to precisely align the feature positions and the hexagonal edges after transferring the mirror material, this step could cause time loss in mass production. Ideally, we want to complete all hexing processes directly on the processing machine. We are currently exploring methods to cut the mirror material on the processing machine itself. Since cutting 45mm-thick mirror material like thin glass by scoring it appears impossible, we are exploring methods such as drilling holes or cutting grooves along the intended fracture line using the machining equipment to ensure reliable breakage at the specified location. Accurate processing time estimates will likely be obtained through prototyping. If this method shows significant potential for reducing processing time, further prototyping will be conducted to establish the cutting method.

Schedule

Thus, the Japanese TMT project is advancing prototyping and preparations for resuming manufacturing across all processes: glass material production, spherical grinding, and hexing. The plan anticipates resuming manufacturing in April 2028 and completing the production of the primary mirror segments, i.e., the hexing stage, by 2035.