

Degradation Mechanism of Molds for Precision Glass Molding

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Precision glass molding (PGM) was developed and introduced in the industry in the 1970s. PGM is a promising technology to manufacture high-quality, complex-geometry optics which are difficult, costly and time-consuming to fabricate using conventional grinding and polishing methods. Typical products are aspherical lenses, freeform lenses and microlens arrays, which are in high demand for applications such as display devices, projectors, cameras, and cellphones, making PGM increasingly popular worldwide. Similar to common molding processes, PGM is based on the shaping of molten glass using predefined molds. The molding takes place at temperatures in the range of 400 to 700 °C, above the glass forming temperature. Simultaneously, high press forces (1–20kN) are imposed. Therefore, during operation, the molds must endure severe thermal, chemical and mechanical stresses. Under such harsh operating conditions, the molds degrade very rapidly. Nowadays, prolonging the service lifetime of the molds and realizing an efficient and economical production is one of the most challenges facing the PGM industry. To achieve this goal, understanding the degradation mechanism of the molds is of vital importance.

In this work, the mold material is made of cemented tungsten carbide with an approx. 650-nm-thick sputter-deposited Pt_{0.3}Ir_{0.7} surface coating on an approx. 20-nm-thick pure Cr intermediate layer. Experimental PGM tests were performed using an industrial PGM machine (Toshiba GMP-211V) with B270[®] glass (Schott AG). The molding temperature is set to be around 640 °C and the pressing force is 1 kN. To better control the boundary conditions, a series of laboratory exposure treatments were also conducted using an in-house designed set-up [1]. Here, the samples of the mold are heated up to 630 °C and held under a well-controlled atmosphere (N₂-2.5%H₂ with +20 °C dew point, P_{O₂}≈1.12×10⁻²³ bar) for times ranging from 0 to 168h. More details about the laboratory degradation experiments are published in [2]. To reveal the degradation mechanism, we applied an array of analytical techniques to characterize the samples from both experiments, including scanning electron microscopy (SEM), (scanning) transmission electron microscopy ((S)TEM), energy-dispersive X-ray spectroscopy (EDX), auger electron spectroscopy (AES) and atom probe tomography (APT).

The key results are summarized in Figure 1. At the initial stage, outbound diffusion and segregation of Cr atoms along PtIr grain boundaries is detected, without distinct changes in the microstructure. After longer exposure times, on the one hand, the bulk reactive interdiffusion between PtIr and Cr layers becomes significant, leading to the formation of an interdiffusion layer at the PtIr/Cr interface. On the other hand, Cr atoms penetrate through the PtIr layer and are selectively oxidized on the surface, forming numerous discontinuous Cr-oxide islands. At later stages, the Cr layer is completely consumed and a chain of nanovoids forms. The continuous supply of Cr to the surface through the grain boundaries allows for the growth of a 30–150-nm-thick oxide scale. Internally, the dissolution of WC substrate takes place, which causes a roughening of the Cr/WC interface. With PtIr moving into these pits and W migrating outbound, complex reactive interdiffusion processes occur, giving rise to a chain of intermetallic particles at the

interfacial region. Although the conditions are different between the experimental PGM tests and the laboratory degradation experiments, the degradation features observed from both types of samples are quite similar [3].

References:

[1] M. Auinger *et al*, Rev. Sci. Instrum. **84** (2013), p. 85108.

[2] Z. Peng *et al*, Corros. Sci. (2017) (Accepted).

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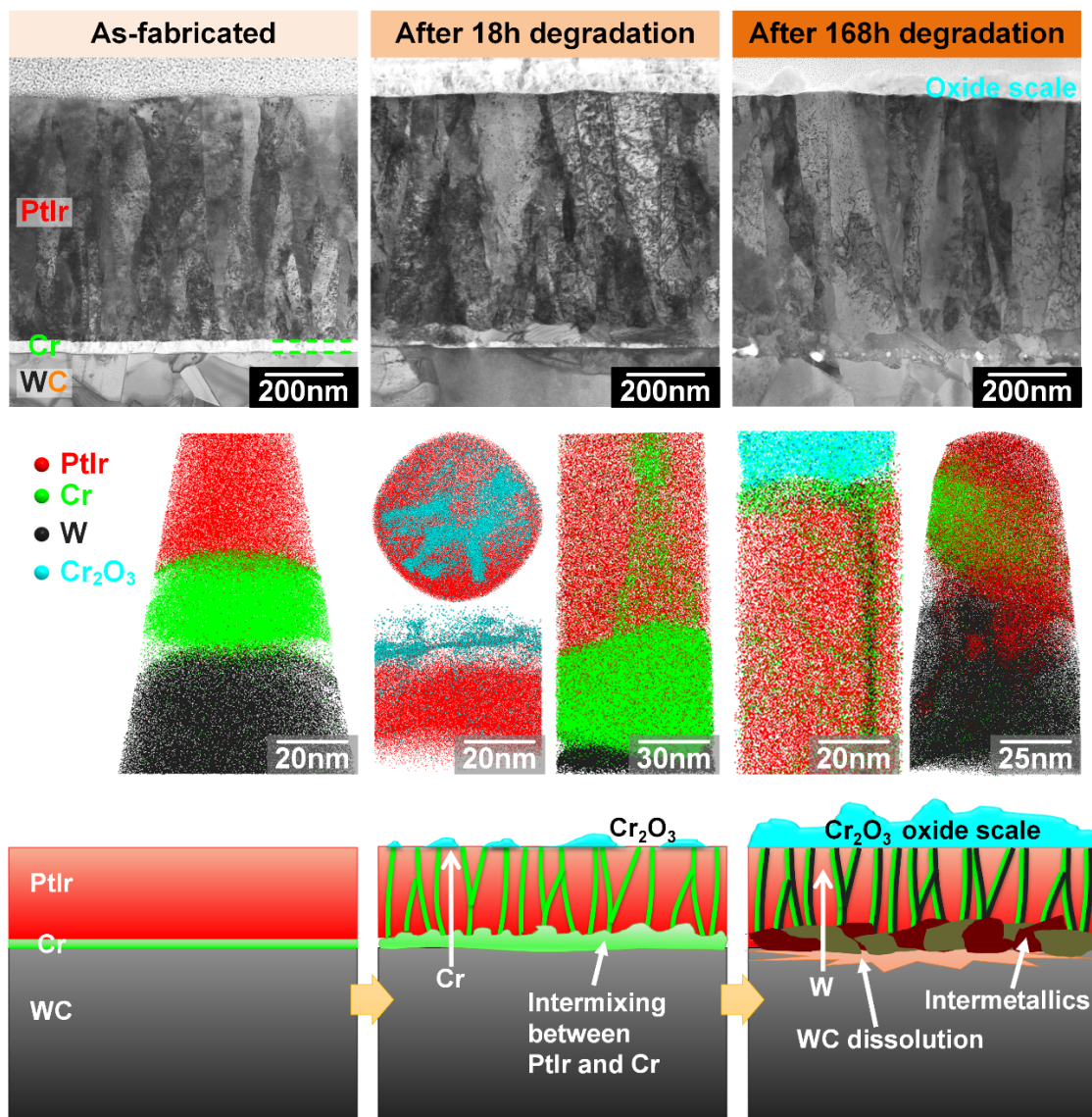


Figure 1. Schematic illustration showing the evolution of mold degradation, supported by STEM and APT results. First, the Cr layer degrades and later also the WC substrate. Outward diffusion of Cr and W through PtIr grain boundaries, Cr oxide scale forming on the surface and intermetallic particles forming at the interfaces are observed.