5 Most Common Mistakes in Designing Precision Super Hard Components

A whitepaper from:

IRD glass

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Executive Summary

For nearly four decades, IRD has been manufacturing precision optical and non-optical components in super hard materials. Roughly 80% of the designs have benefited from IRD's proprietary Design for Manufacturability (DFM) Review.

During these reviews, IRD technical staff and customer designers consider material selection, design features, and specifications in the context of total cost and quality of the component.

This white paper documents the most common opportunities identified by the IRD technical team for improving designs of parts from super hard materials for both optical and non-optical applications.

Introduction to Super Hard Materials

Super hard materials are polycrystalline compounds commonly formed from metal oxides, nitrides and carbides. These materials are sometimes referred to as oxide and non-oxide ceramics.

Super hard materials feature a combination of hardness, wear resistance, and chemical inertness, among other properties, not available from metals. Some super hard materials, notably Sapphire, Aluminum Oxynitride, and Spinel, are also transparent at wavelengths in the visible and near to mid infrared portions of the electromagnetic spectrum.

As with metals, the material properties of super hard materials can be tailored for various properties through their microstructure which is defined by grain size, shape and orientation; porosity; and the presence and amount of any secondary phases.

The most common super hard materials used in manufacturing customer-designed precision components by IRD are shown in the table below.

Alumina
Aluminum Oxynitride (ALON)
Sapphire
Silicon Carbide
Silicon Nitride
Spinel
Zirconia

Challenging Yet Manufacturable

The higher hardness, wear resistance, and brittleness of super hard materials compared to metals create different manufacturing challenges than those faced when producing metal parts.

The first challenge comes from the additional time needed to machine and finish these materials. Given their brittleness, super hard materials must be fabricated with special care to achieve the required surface quality and tolerances.

There is also a lack of standardization among the various materials. This means that it is even more critical to specify the material properties needed for the application and ensure that they are consistent from lot to lot. Standard shapes and sizes of super hard materials are limited compared to their metal counterparts.

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One more wrinkle in manufacturing parts from super hard materials is that the key properties, such as tensile strength, compression strength, hardness, and scratch resistance, can vary significantly with grain size, porosity, or crystal orientation.

Nonetheless, these challenges are routinely managed as evidenced by the growing number of parts from super hard materials. One key to success is having a close working relationship, or partnership, between the designer, material supplier, and manufacturing partner.

Many and Wide-Ranging Applications

Super hard materials are used in a wide and growing range of applications. The industries represented in today's applications include automotive, aerospace, electronics, medical devices, semiconductor and a host of others.

Some of the applications for which IRD has manufactured customer designed components are:

- Optical – For heavy use, scratch-prone optical applications, Sapphire provides scratch resistance and is one of the only materials that will transmit a high percentage of light in the visible and near and mid-IR bandwidths as well as portions of UV. Applications include:
    - Agricultural equipment - Sapphire windows are used to protect the viewport in optical seed counters used on planting equipment.
    - Inspection stages - Sapphire provides good transmission for bottom surface illumination while also preventing damage to the stage due to scratches caused by the part being measured.
    - Equipment for desert applications - Sapphire is used for sensor window covers that will resist damage even in harsh conditions including blowing sand and frequent cleaning.
    - Petroleum and chemical processing sensors – Due to the hazardous and volatile nature of their environments, most, if not all, chemical and flame detection sensors incorporate Sapphire windows in explosion-proof enclosures. These windows carry extremely tight tolerances and must be thoroughly tested to ensure viability within these settings.
- Medical and dental devices – Super hard materials such as Sapphire and Zirconia provide biocompatibility, wear resistance and toughness for numerous medical and dental implants.
- Extreme wear applications - Sapphire, Zirconia, Alumina, Silicon Carbide and Silicon Nitride are especially resistant to wear due to their extreme hardness. Applications include nozzles, blades, end effectors, solder plates, feedthroughs, brake parts, bearing races, and watch gears.
- Chemical processing and handling equipment - Zirconia and Alumina are often used as valve seats for corrosive chemical handling systems due to their chemical inertness.

Figure 1: Examples of customer designed parts produced from super hard materials by IRD.

New applications continue to emerge as the capability to manufacture precision components from these materials expands.

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Mistake #1 - Including unnecessary complexity – While features such as contours, pockets, and threads are relatively simple to produce in metal components, these same features can add substantial cost to a super hard material part. All pockets and blind features must be machined. Machining tight tolerance threads in super hard materials is difficult; producing fine threads even more so.

IRD guidance - Wherever possible, maintain basic geometries. While it is clearly possible to contour machine a super hard material, it takes much longer and increases tool costs due to the high tool wear. Also, allow room for radiused interior corners.

When threads are required, a better approach to machining threads in the super hard material is to press-in a metal insert that contains the threads. Dimensions of the hole will need to take into account the coefficients of thermal expansion of the super hard material and insert material. Also, the tolerances of the hole in the super hard material and of the metal insert will need to be tight since the ceramic does not plastically deform as metals do.

Mistake #2 - Over specifying surface finish – It's a simple relationship - the tighter the required surface finish, the longer the cycle time to machine a super hard material component.

IRD guidance - For polished optical surfaces, a finish of 60/40 is the most cost effective. Areas that require better finishes, such as 20/10 or 10/5, should be limited to those for which the finish is necessary for the proper function of the part.

For other polished surfaces, a surface finish of 10 Å can be consistently achieved. However, specifying a better finish can significantly increase cost.

The most common finish specified for ground surfaces is 32 micro inches (0.81 μm) or greater. While it is possible to achieve a better finish, such as 10 or 20 micro inches, this finish will come with a higher cost that depends on the specific material and dimensions.

Mistake #3: Over specifying the level of precision - Tight tolerances require fine grinding or other finishing operations that typically rely on a low material removal rate to achieve repeatable quality in production.

IRD guidance – To control cost, confine the size and complexity of surfaces for which tight tolerances are specified to those requiring it. For applications requiring precision, maintain tolerances for large surfaces to ±0.1 mm (±0.004 inch) and ±0.05 mm (±0.002 inch) for smaller dimensions.

If you do specify tighter than ±0.05 mm, make sure that it is for a surface which can be ground flat.

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Mistake #4: Failing to include clearance features for downstream assembly operations - Despite the extreme hardness of the material, sharp edges can be brittle, creating opportunities for fracturing and edge chips if there are tight mating surfaces in future assembly operations. Adding sufficient relief, clearance, or chamfers to edges will simplify the assembly work and produce better results for the overall value stream.

IRD guidance – If a chamfer is beneficial, it is best to specify 0.38 mm (0.015 inch) or greater. Calling for a chamber of 0.13 mm (0.005 inch) or less will increase the manufacturing cost.

Mistake #5: Specifying the wrong material or specifying the material incorrectly – Since the cost and functionality of a super hard material component are often closely tied to the specific material, it is important to specify the correct material from the beginning. Changing materials in the prototype phase or later will most likely be costly.

IRD guidance – It is important that the designer understand the properties of the super hard material that are critical to their design. Most super hard ceramic and sapphire materials are available in many different grades or crystal orientations which can affect the final cost and manufacturability of a component.

That there is a serious lack of standardization of super hard materials is the basis for another reason to be careful when specifying the material. For example, one does not necessarily know the properties to expect from a super hard material of a certain purity. This makes it especially important that the designer work with material suppliers and its manufacturing partner upfront to have the best opportunity of selecting the correct material from the beginning.

Some general guidelines for selecting materials for these applications are:

- Try to find material suppliers who offer material in standard shapes such as rods and plates since these are typically much less expensive than custom molded blanks.
- For sizes over 100 mm (4 inches), material costs generally start to rise exponentially.
- Check out the [Ceramic Industry Buyers Guide] which includes information about the most common materials.

Case Study: Precision Flat Polished Sapphire Window for Photonics

Optical grade sapphire windows less than 10 mm (0.4 inch) diameter and from 0.5 to 2 mm (0.02 to 0.08 inch) thick are widely used in photonics applications. Nevertheless, documenting specifications that support both cost and quality goals remains a common challenge when designing sapphire windows and other super hard material components.

For example, the customer in this case study initially presented a design that simply specified "no chips", an unreasonable goal given the inherent brittle nature of sapphire, especially for a window produced in quantities of up to 10,000 units per month. All that one has to do to find a chip is to keep increasing the magnification of the inspection microscope.

The technical teams from the customer and IRD initially met to discuss the window's application and its real quality requirements. Through the Design for Manufacturability (DFM) Review, the teams agreed upon a chip specification of less than 125 μm (0.005 inch).

The DFM review also revealed that the application demanded a surface finish much tighter than a scratch/dig value typically associated with optical surfaces; the team agreed on a surface finish specification of 10 Å (0.039 μin). They also agreed on methods for measurement of each of the specifications.

Once the specifications and inspection methods had been defined, IRD began to develop lapping and polishing processes that would meet the specifications and cost targets in volume production. Using Design of Experiment (DOE) methods, the IRD production team identified optimum levels of surface finish to achieve at each of the process steps in order to minimize overall processing time and maximize consistency.

Along with developing lapping and polishing processes, IRD defined measurement methods involving high magnification microscopes for precise chip measurement. They also incorporated profilometers and white light interferometers for precise in-process measurement and control of surface finish.

Through close collaboration with the customer, IRD was able to go from prototyping (100 first article windows) through pre-production (1,000 windows) and into production (5,000-10,000 windows per month) within the customer's short schedule, all while reliably achieving the agreed-upon specifications.

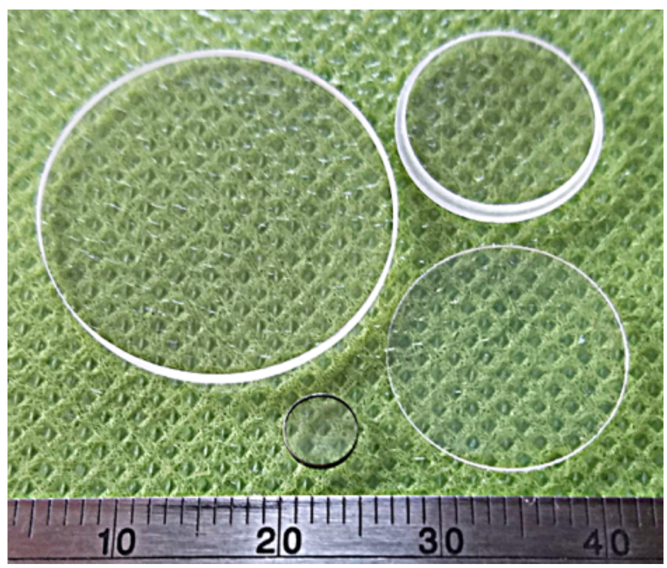

Figure 2: IRD produces sapphire windows of various sizes for photonics applications. IRD processes are able to consistently achieve a 125 μm (0.005 inch) maximum chip specification and optical surface finish of better than 10 Å (0.039 μin). Scale in millimeters.

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IRD Glass has maintained a 98%+ on-time delivery rate for more than a decade. Reports from customers in industries as diverse as aerospace, medical devices, telecommunications, and semiconductor equipment testify to IRD's position as a leader in precision custom optics manufacturing.

Contact IRD whether you are considering designing parts from super hard, ceramic or glass materials or have an existing design for which you are looking to develop a second source.

For your new design, IRD will provide a no-cost Design for Manufacturability Review. The technical team will review the design to ensure that it can be produced with the optimum cost, quality, and consistency.

If you wish, IRD will provide a cost estimate for prototype and production volumes. For designs that are currently in production, IRD engineers will show you the benefits of their consistent, industry-leading quality and on-time delivery for your components.

"Your biggest challenges are our biggest successes!"

About IRD

Minnesota-based IRD has been manufacturing precision glass and ceramic components since 1982. The company has two sites:

- IRD Glass in Litchfield, Minnesota – 20,000 square feet (2,000 square meters) with a 10,000 square foot (1,000 square meters) addition currently underway.
- IRD Ceramics in Alexandria, Minnesota – 10,000 square feet (1,000 square meters).

The company's 75+ employees proudly serve some of the most demanding global customers including Honeywell, TDK, Rockwell Collins, 3M, CyberOptics, Trumpf, Alcon, L3, and Agilent. Steady growth of 10% year-over-year for the last 5 years has come from long-term partnerships and strategic manufacturing agreements in which IRD has manufactured custom designs of optical components.

While the company does not design optical components, it works closely with its customers' designers and engineers to create designs that most cost-effectively and reliably provide the required performance.

Recently, IRD has expanded its manufacturing capabilities, including investments for sapphire windows, precision components and laser reflector cavities.

IRD is veteran-owned, ITAR registered and holds several certifications, including ISO 9001:2015.