Proc. of SPIE Vol. 1168, Current Developments in Optical Engineering and Commercial Optics, ed. R E Fischer, H M Pallicove, W J Smith (Dec 1989)

New technology for beryllium mirror production

Roger A. Paquin

Electro Optics Technology Division
The Perkin-Elmer Corporation
Danbury, Connecticut

ABSTRACT

Current methods for fabricating beryllium optics are both time consuming and too expensive for many production applications. This has sometimes resulted in the substitution of marginally acceptable materials which do not always deliver the required performance. The advent of net shape blank fabrication directly from powder, utilizing disposable tooling and the hot isostatic pressing process, has provided the breakthrough which enables the cost effective production of beryllium mirrors.

1. INTRODUCTION

It has been recognized for many years that beryllium (Be), because of its unique combination of mechanical, thermal and optical properties, as shown in Table 1, is the best choice for weight or inertia sensitive applications. When the application is for low temperature infrared optics, the choice is clearly Be due to the combination of high reflectance, high thermal conductivity, the highest stiffness to weight ratio of any material, and low thermal expansion combined in a relatively ductile (not brittle) material. However, because of the relative difficulty and the high cost of fabrication of Be, it has not been used as

TABLE 1
PROPERTIES OF MIRROR MATERIALS

MATERIAL	ρ DENSITY (g/cc)	E YOUNG'S MODULUS (GPa)	E/ρ SPECIFIC STIFFNESS (NORMALIZED)	CTE (ppm/K)		K THERMAL CONDUCTIVITY (W/cm-K)		THERMAL DIFFUSIVITY (cm^2/S)		THERMAL DISTORT. COEFF.			
										CTE/K STEADY STATE (10^{6} cm/W)		CTE/D TRANSIENT (10^{6} S/cm^2 K)	
				300K	150K	300K	150K	300K	150K	300K	150K	300K	150K
DESIRED	LOW	HIGH	HIGH	LOW	LOW	HIGH	HIGH	HIGH	HIGH	LOW	LOW	LOW	LOW
BERYLLIUM	1.85	287	100	11.4	3.4	1.93	3.16	0.57	2.69	5.9	1.1	20	1.3
FUSED SILICA	2.19	72	21	0.5	-0.17	0.014	0.010	0.01	0.01	36	17	59	15
ULE	2.21	67	19	0.02	-0.57	0.013	0.010	0.01	0.01	1.2	57	1.9	57
ZERODUR	2.53	92	23	-0.09	-0.18	0.016	0.012	0.01	0.01	5.7	15	12	16
SILICON CARBIDE (ALPHA)	3.22	425	85	3.4	0.4	1.4	1.15	0.65	1.42	2.4	0.3	5.2	0.3
SILICON CARBIDE (BETA)	3.21	420	84	2.4	0.89	1.10	2.0	0.875	2.7	2.2	0.4	2.7	0.3

extensively as its properties would dictate.

Beryllium has been used when there is no other choice, such as in weight-critical orbiting payloads and fast scanning mirrors. For most SDI applications, where nuclear hardness is a critical requirement, Be is must be used. Some of these applications require hundreds and even thousands of mirrors and current production methods are not cost effective. The balance of this paper compares the more conventional Be mirror fabrication methods with new techniques based primarily on the hot isostatic pressing (HIP) process.

2. THE OLD WAY

For many years, Be mirrors have been made by machining the blanks from vacuum hot pressed (VHP) block. This block is made by pressing powder in a die to form a cylindrical billet, from which all other forms are cut. Sometimes this can be very costly since most of the billet can end up as machined chips[1]. The very successful IRAS (InfraRed Astronomical Satellite) telescope[2] shown in Figure 1 was made in this manner, but it was one of a kind. In production, components like the advanced inertial reference sphere shown in Figure 2 are extremely expensive because of the hundreds of machining operations required to transform a solid block of beryllium into the complicated component shown in the figure. Even relatively simple, flat scanning mirrors are made in this same way by machining, one at a time from solid block. There is a better way.

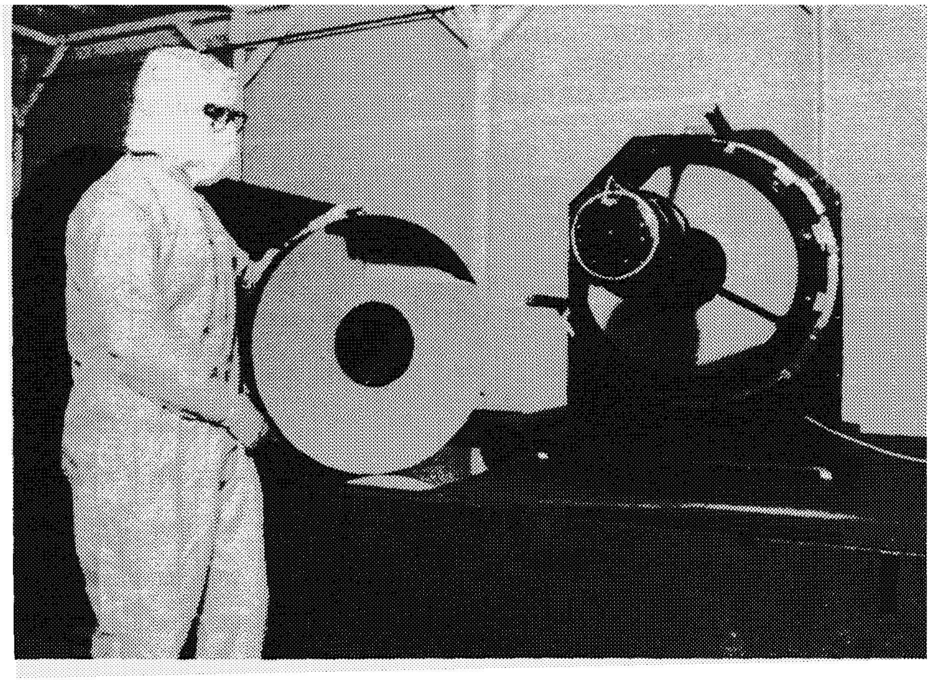

Figure 1. Infrared Astronomical Satellite (IRAS) telescope machined from vacuum hot pressed beryllium billets.

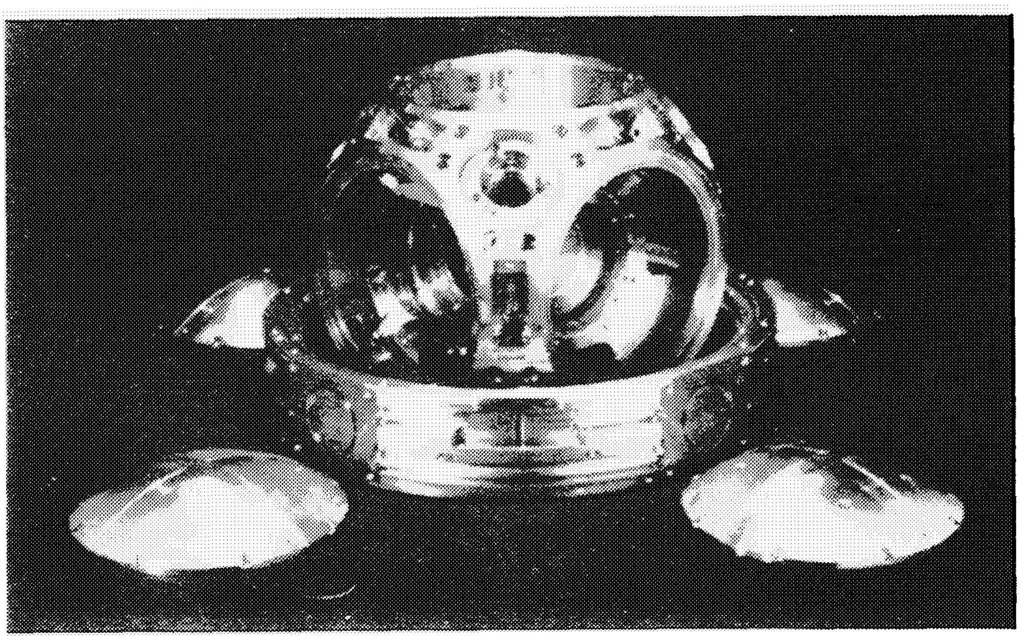

Figure 2. Beryllium advanced inertial reference sphere and related components for the MX missile.

3. PRODUCTION BLANK FABRICATION TO NET SHAPE

3.1 Background

For most metals, net shape fabrication means casting, a perfectly acceptable method for making aluminum and copper mirror blanks. But it doesn't work for Be because the cast grains are very large and brittle, there is little intergranular strength, and there is often cracking in the casting. Forging of preforms or near-net shape components is also possible with other metals, but not Be because of its high hot strength. The most direct way of making net shape Be mirrors is the direct compaction of powder to form the part.

Direct compaction to net shape can be accomplished in a number of ways ranging from simple, one-step HIP to multi-step processes such as cold isostatic pressing (CIP) in a shaped rubber bag followed either by vacuum sintering or HIP. The two-step processes are designed to minimize shrinkage in the hot part of the cycle by cold pressing to shape and near full density, but the cold pressing introduces plastic deformation of the powder particles which results in some anisotropy of properties in the finished part. The one step direct HIP process should then provide the best combination of material properties, shape control, cost and schedule. We have chosen to develop this process for the fabrication of Be mirror blanks and precision structures.

3.2 HIP development

We started the development of methods to fabricate net shape Be mirrors directly from powder in 1979, and produced lightweight sandwich construction mirrors with honeycomb cores and improved properties a few years later[3,4]. Figure 3 shows two 9.5-inch blanks which were produced and tested. One was polished to 0.06-um rms flat while the other was sectioned for testing. The partial blank, which has not been machined, demonstrates the net shape capability of the process. Tooling which can withstand the HIP temperature and pressure, and which can be selectively dissolved away, is used to form what will be the voids in the component. This unique tooling method[5] provides the uniform core structure demonstrated in the x-ray radiograph of Figure 4 as well as facesheet flatness (internal) of 30 to 40-um. We have produced several larger mirrors using this technique and can now fabricate mirrors up to 1.5-meters diameter with area densities as low as 15-kg/m^2. Since the HIP process uses lower temperatures and shorter times than the VHP process, better mechanical properties and improved homogeneity and isotropy of properties can be achieved. Typical property improvements are listed in Table 2 for HIP'ed IP-70A over VHP I-70A.

3.3 Production methods

For smaller, simpler mirrors, production rates can be

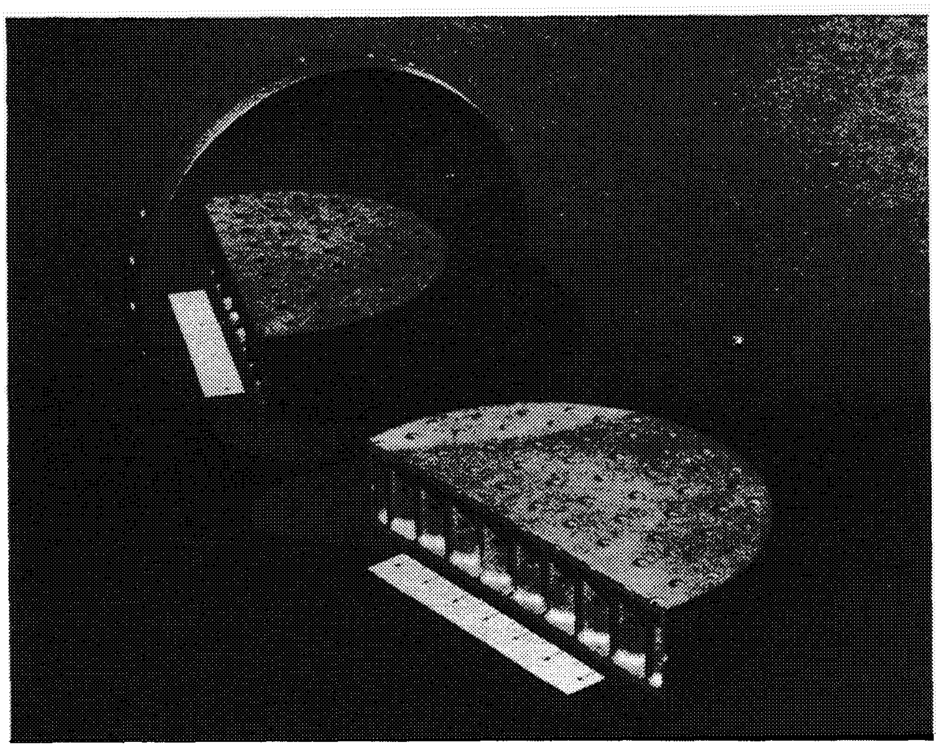

Figure 3. Beryllium mirror blanks, 9.5-inch diameter, produced by HIP process directly from powder.

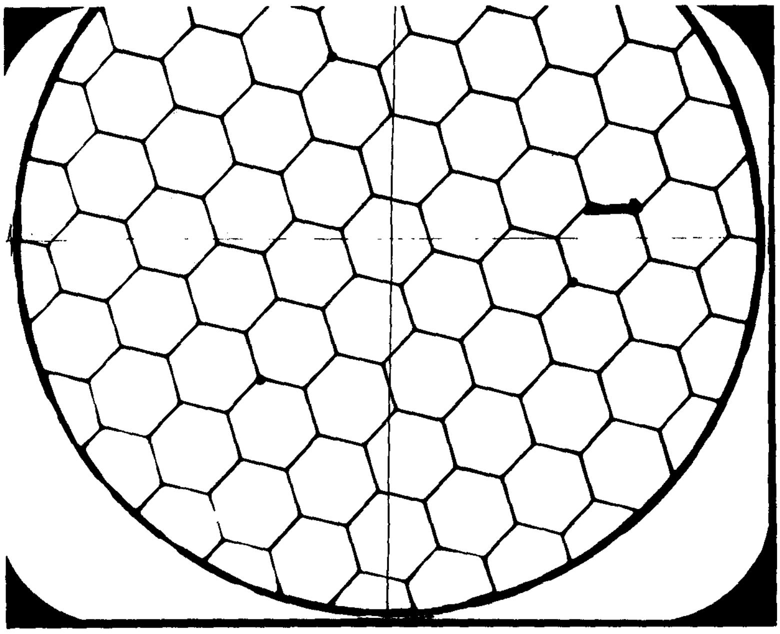

Figure 4. X-ray radiograph of the polished mirror of Figure 3 showing uniformity of internal core structure.

TABLE 2
COMPARISON OF THE PROPERTIES OF I-70A BERYLLIUM
HIPed COMPARED TO VACUUM HOT PRESSED

PROPERTY	HIP	VHP	IMPROVEMENT
ANISOTROPY (PPM/K)	0.03	0.13	77.0%
MICROYIELD STRESS (KSI)	3.8	2.6	46.2%
0.2% OFFSET YIELD STRENGTH (KSI)	44.6	25-30	48.7%
ULTIMATE STRENGTH (KSI)	68.9	35.0	96.9%
ELONGATION	3.8%	3.0%	26.7%
YOUNG'S MODULUS (MSI)	41.2	42.0	-
POISSON RATIO	0.08	0.09	-

achieved by using a variation on this process. For example, a thin shell mirror with simple mounts can be fabricated in quantity by providing shaped tooling between layers of Be powder to form a stack of mirror blanks in one container as shown in Figure 5. Many blanks can be fabricated in one container, the overall aspect ratio (height:diameter) of the container determing the

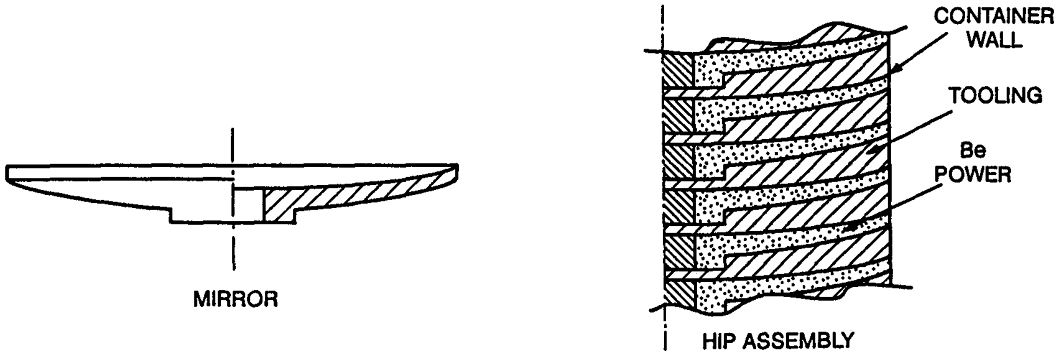

Figure 5. Schematic diagram of a concept for the production of beryllium mirrors directly from powder using soluble tooling and the HIP process.

actual number per can. Many of these containers can be HIP'ed at the same time since autoclaves are available with workspace volumes as large as 65-inches diameter by 105-inches deep[6].

After HIP, the entire container is immersed in nitric acid, which dissolves both the container and tooling material but does not effect the Be parts. A minimum of machining is required, just enough to remove any flashing and add fine details such as mounting holes. After stress relief annealing and a light etch, the blanks are ready for optical finishing.

The complexity of the mirror blanks fabricated in this manner is limited only by the ingenuety of the tool designs. Tooling can be fabricated by net shape forming methods such as hot or cold forging, blanking, spinning, machining, etc., and combinations of these methods. While the technology is new, there are no mysteries, and components can be fabricated in production quantities now.

4. PRODUCTION OPTICAL FINISHING

Grinding and polishing of small flat and spherical Be mirrors at production rates are only slightly more difficult than glass components, and can utilize the same high speed procedures with only slight modifications. Diamond, cubic boron nitride, silicon carbide or alumina, oil or buffered water slurries on metal (grinding) and pitch (polishing) laps are recommended. For on-axis aspheres, similar tooling and slurries are used, but in a plunge grinding and polishing mode. Using these methods, high quality, low scatter beryllium mirrors can be fabricated at production rates.

5. CONCLUSIONS

New technology has been developed which utilizes soluble tooling and the HIP process which can now be used to fabricate multiple Be mirrors and components directly from powder. The methods are simpler and much more rapid than prior methods, and can yield parts at higher rates and lower cost than has been possible up to now.

6. REFERENCES

1. R.R. Altenhof, "Design and manufacture of large beryllium optics," in Design, Manufacture and Application of Metal Optics, W.P Barnes, Jr. ed., Proc. SPIE 65, 20 (1975)

2. M. Schreibman and P. Young, "Design of infrared astronomical satellite (IRAS) primary mirror mounts," Opt. Eng. 20 (2), 190 (1980)

3. R.A. Paquin, et al, "Advanced lightweight beryllium optics," Opt. Eng. 23 (2), 157 (1984)

4. R.A. Paquin, Hot isostatic pressed beryllium for large optics," Opt. Eng. 25 (9), 1003 (1986)

5. G. Gould "Method and means for making a beryllium mirror," U.S. Patent No. 4,492,669 (Jan. 8, 1985)

6. L.M. Sheppard, "Predicting HIP's future," Adv. Materials and Proc. 2 (3), 24 (1986)