ENABLING MICRON LEVEL MOUNTING ACCURACY

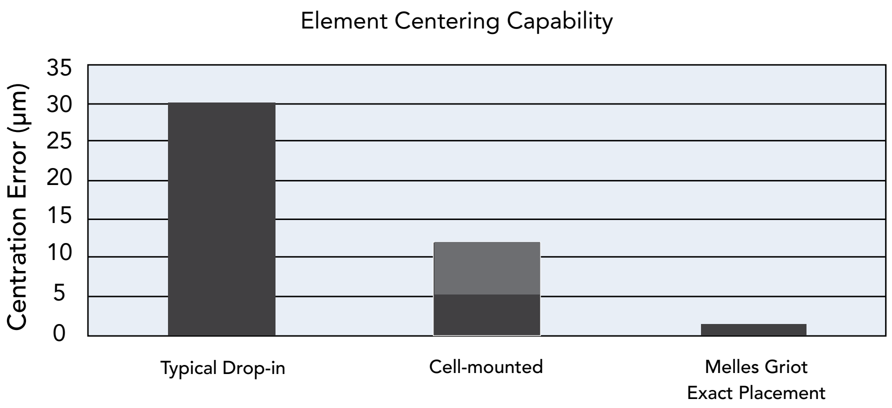
MELLES GRIOT EXACT PLACEMENT™ LENS ASSEMBLY TECHNOLOGY

There is an ever-increasing demand for diffraction-limited high performance lens assemblies as the optical systems in which these lenses are used are becoming more complex and sophisticated. With the drive to smaller and smaller structures in the semiconductor industry, for instance, the tighter design rules require defect and feature size inspection and verification by the highest performing imaging systems currently available. Newly emerging life science and medical optics applications from digital pathology to DNA sequencing also require high-end objectives with the highest levels of resolution and sensitivity.

These lens systems must provide an extremely high level of performance such as high numerical aperture, large field angles, broad spectral bandwidth, and extreme (or perfect) wavefront correction—often pushing the limits of what is possible. This makes them highly sensitive to all sources of manufacturing errors, especially to lens alignment and airspaces. Therefore the challenge is not only to create compatible lens designs, but to manufacture and mount them so that the level of performance designed into the lens is maintained in operation in the as-built "real" system.

Melles Griot, with forty-years' experience in optical systems, deep technical expertise, and creative engineering teams, has developed the manufacturing processes and tools to enable the production of such high performance lens assemblies. Melles Griot's proprietary Exact Placement assembly technology makes it possible to position and align each optical element within the lens system to micron level accuracies. Backed with engineered compensation techniques and integrated metrology, it allows for multielement lens assemblies to be built in an ultra-precise, predictable, and repeatable process to meet the most extreme performance requirements.

In this paper we will review the different lens assembly techniques, how they should be selected depending on the required level of positioning accuracy, and how the Exact Placement technology specifically addresses the requirements for the tightest possible tolerances.



Lens mounting considerations

In the development and production of multielement lenses or optical systems, the process of turning the optical design into fabrication prints is often the most difficult part. Rigorous optical tolerancing and design simulation are essential to defining all manufacturing tolerances and compensators, and to be able to accurately predict the final optical performance of the fully integrated as-built opto-mechanical system. This process is closely tied to specific manufacturing experiences and requires close collaboration with all functional groups including Fabrication, Assembly, and Test.

The mounting of the lenses is a major consideration in this process. The lens barrel—mechanical structure that holds the complete lens assembly—must be designed to ensure the proper axial and radial positioning of the different optical elements (Figure 1). First, the elements must be mounted so that the centers of curvature of all the optical surfaces fall on a common line called the optical axis: this is what we refer to as radial positioning or centration. Additionally, the elements must be positioned with respect to each other so that the specified airspaces are achieved: this is axial placement.

The barrel design, with the choice of the optimum mounting configuration for the optical elements, is very specific to each lens design. It depends not only on the required positioning accuracy, but also on the overall system requirements including weight and mechanical envelope, environmental conditions, volume and cost.

Nevertheless, a thorough understanding of the mounting techniques and production capabilities is required to fully account for all the uncertainties that come from real world manufacturing and operation environments. Otherwise the most sophisticated optical design will not achieve the desired performances in operation.

This is of critical importance for the production of high-end optical systems, since the image quality is today mainly limited by the achievable centration accuracy and air gap tolerances at the micron level. Modern lens design programs indeed make it possible to develop theoretically quasi-perfect complex lenses. The capability for surface accuracy was also improved during the last years, for instance with the use of Magneto Rheological Finishing (MRF®) to provide optical surfaces with irregularities better than $\lambda/60$ PV. Therefore, in-depth analysis of all sources of inaccuracy in the mounting and assembly process, along with state of the art manufacturing and measuring technologies, are essential to be able to achieve the highest precision and to successfully build such demanding lens assemblies.

After a first overview of the most common lens assembly techniques, we will look in more detail at the specific fabrication and assembly tolerances that affect the relative positioning of the optical elements within the assembled system. Other factors such as thermal effects or vibration will not be discussed, but must be considered during the barrel opto-mechanical design to ensure that the centration and prescribed airspaces are maintained in operation.

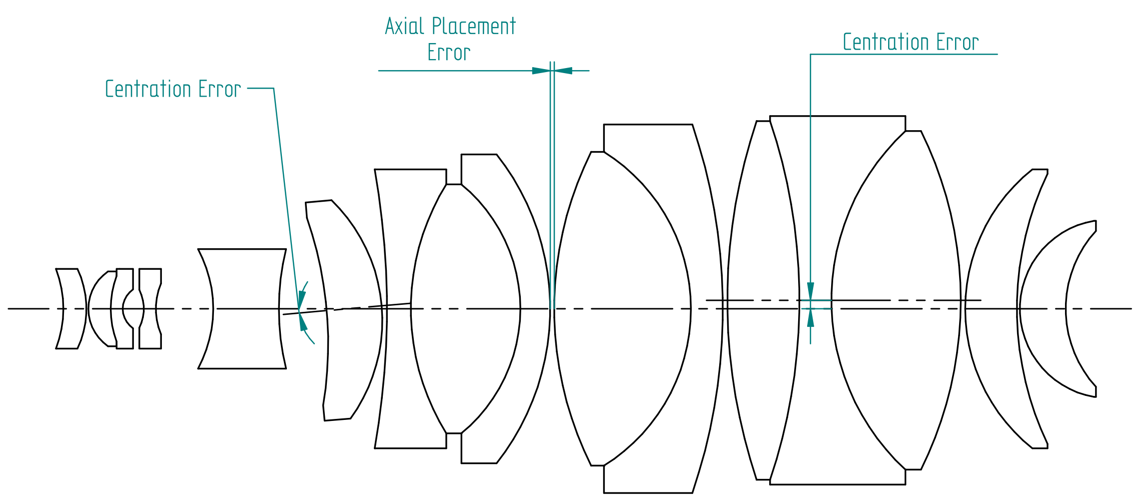


Figure 1: Multielement lens assembly with incorrect element placement: the optical axes of the elements do not coincide with the axis of the barrel and the airspaces are not correct.

Lens assembly techniques and performance

In Figure 2, typical examples of opto-mechanical designs are shown, representing the different types of lens assembly techniques commonly used in the industry and with the corresponding level of placement accuracy.

The conventional drop-in assembly, based on the edge mounting lens construction, offers fair performance (≈30 µm). It is appropriate for most standard applications not requiring extreme accuracy, even though it can also be used for higher precision multielement lens assemblies by making the tolerances sufficiently tight.

The cell-mounted arrangement allows for improved element alignment accuracy, down to about 5 µm. It is commonly employed for high performance systems where the optical quality depends more strongly on the precise positioning of the optical elements within the lens assembly.

However, when it comes to very high performance complex optical assemblies, even small deviations in the 5 µm range can have a detrimental effect on the imaging quality. Typical applications range from semiconductor lithography and wafer inspection to life science imaging. To achieve the highest throughput in subcellular high-contrast and fluorescence imaging for applications like high-content screening, digital pathology, and DNA sequencing, high-NA objectives must exhibit superior wavefront performance over very wide fields of view and broad wavelength ranges. This sensitivity to extremely tight tolerances requires further improvement with the placement accuracy.

Melles Griot developed the Exact Placement lens assembly technology to overcome the limitations of the drop-in and conventional cell-mounted techniques— making it possible to meet the increasing demand on imaging performance. It allows for multielement lens assemblies to be built such that each optical element is placed relative to an ideal axis to accuracies on the order of 1 µm!

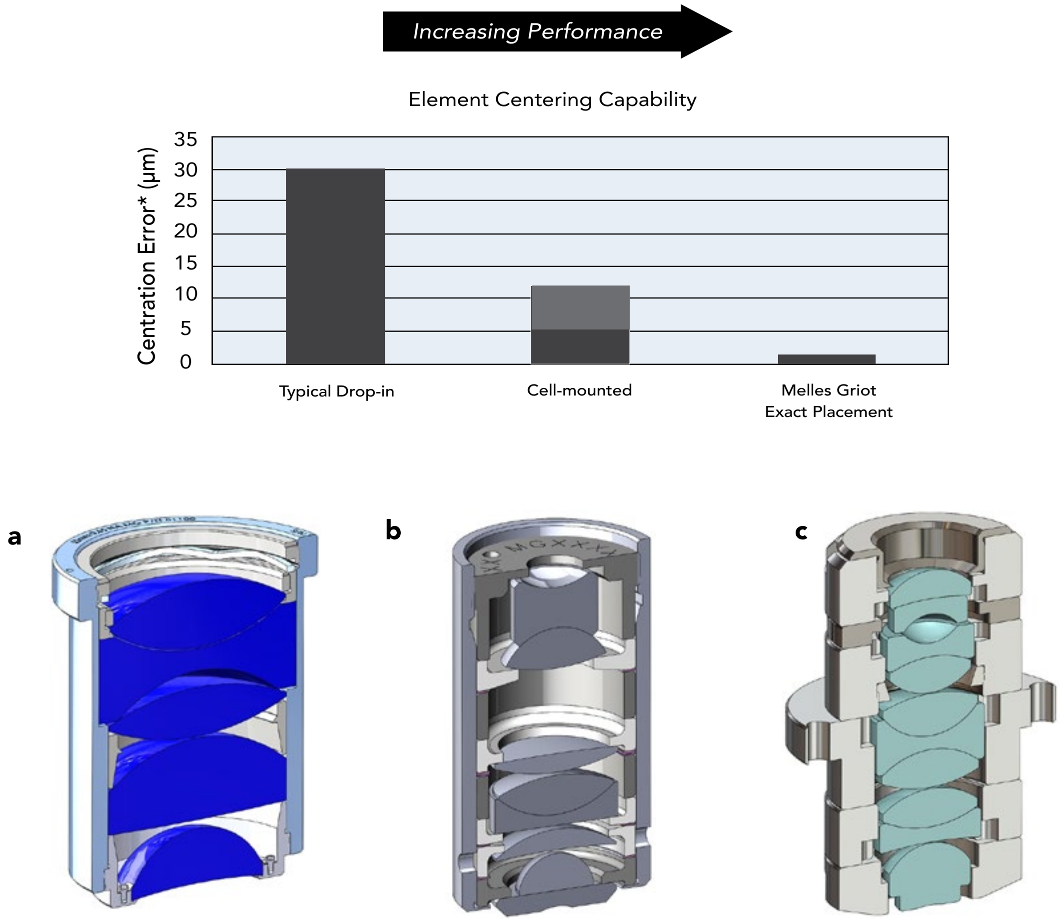


Figure 2: Melles Griot Exact Placement assembly technology enables a much higher level of positioning accuracy than the drop-in and conventional cell-mounted construction methods.

** "Centration Error" is measured as a surface-normal TIR (Total Indicated Runout) at the edge of the clear aperture*

Drop-in assembly

In the conventional method, the optical components and mechanics are fabricated to prescribed dimensions and tolerances, and assembled without further machining and without adjustment. A typical example is shown in Figure 2a. The lenses are separated with spacers and are typically held in place with a simple retaining ring. This technique has been called "drop-in assembly"[1], referring to the fact that the lenses are simply dropped in place with no special care taken to align them within the mount. Stepped barrels can also be used to accommodate lenses with varying size, in which case the lenses are individually mounted in the recesses (lens seats) bored inside the mount.

This is a simple method to implement, and many commercial applications, such as machine vision or camera lenses, use this mounting concept. It is appropriate for small quantities up to high-volume production since the assembly can be automated. However, tight tolerances for the machining of the metals and edging of the lenses are required to achieve high performances, and the achievable level of accuracy is limited, with typical element positioning precision in the range of 10 to 30 microns.

Let's look in more detail at how each element interacts with the mounting mechanics and interfacing surfaces in a drop-in design. The positioning of the lenses is generally modelled by considering that they are edge-mounted or "edge-centered,"[2] which is that they are centered by the contact of their edge to the inside diameter (ID) of the mount. As shown on the model in Figure 3, each lens rests on a seat (which can be a spacer or shoulder) and can "roll" until the edge touches the ID of the metals; unless the axial preload and cupping angles are sufficient to get the lens element self-centered.[2]

To ensure precise alignment of the lenses, all the lens diameters must closely match the inside diameter of the mount, and all lenses must be precisely edged (no wedge). High precision is also required on the spacer parts and lens seats so as not to generate additional element tilt and decenter, as well as to control axial spacing. When straight barrels are used, the precision is limited mostly by the precision of the lens elements and the stack up of errors. With stepped barrels the mounting tolerances for each lens element can be accounted for separately and therefore somewhat more accurately; however, more complex machining is required.

Cell-mounted assembly

Cell-mounted designs are often implemented to overcome the very tight tolerances that would be required with a drop-in design concept. In this assembly technique, the lenses are mounted and precisely aligned within individual subcells and then stacked in a barrel like poker chips. This has also been referred as "poker-chip assembly"[1] or stacked-cell assembly. A typical example is shown in Figure 2b. The cell-mounted construction offers the advantage of an intermediate mounting step to relieve some of the fabrication tolerances of the glass or metal parts.

Several methods have been developed to ensure the precise alignment of the mounted lens (in relation to the subcell's axis). The three main approaches are described below. The lens element can be "pre-aligned" in the subcell either through active adjustment or by tightly controlling the diameter fit so that it gets centered. In the last case, the lens element is mounted without special care and the alignment error is corrected by machining the subcell.

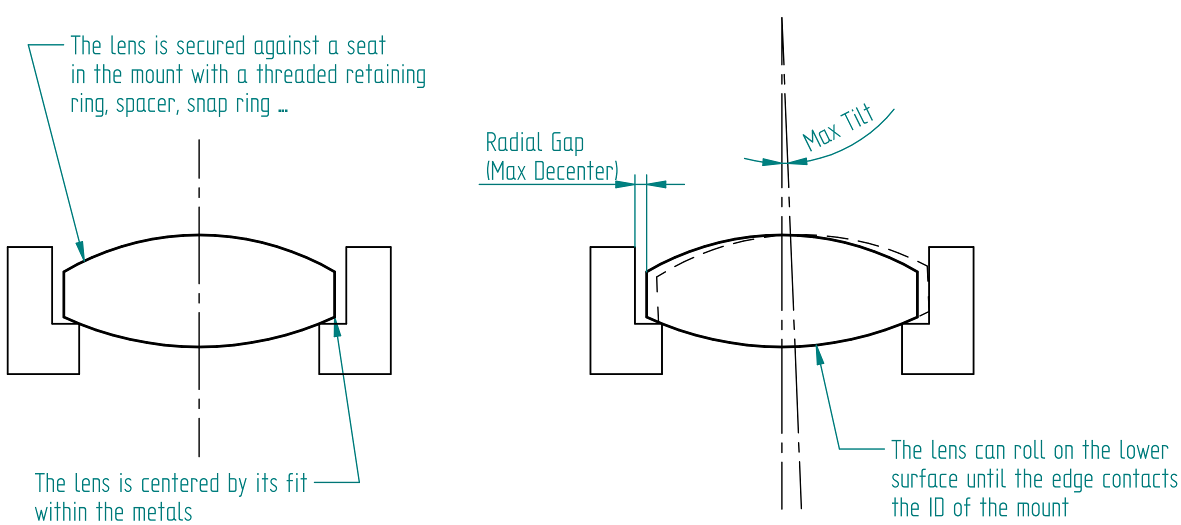


Figure 3: Drop-in or edge-mounted construction: the element can roll and is aligned by its fit within the metals. Lens wedge and diameter affect element placement accuracy.

Active element alignment
In the commonly used potted assembly construction, the lens element is actively aligned within its subcell and bonded it in place with a thin layer of compliant adhesive (Figure 4). In general the element is seated on a precision metal subcell and mounted against an active spherical surface. The position of the top surface is then adjusted so that it gets aligned to the mechanical axis of the subcell.

The benefit of this technique is that relatively loose tolerances can be used for the element centering and edging and for the metal bore diameter. Provided there is sufficient clearance between the element OD and the subcell ID, the lens wedge is compensated by the active alignment as the lens is allowed to “roll” with the subcell.

However, it does not allow adjusting the position of the lower lens supporting surface. The lens seat therefore has to be accurately machined as any tilt or decenter will cause a combination tilt and decenter of the lens element. Tight tolerances are also required on the subcell thicknesses to ensure precise axial positioning and to achieve the specified airspaces.

In addition, one must consider the stacking errors, which is how well the different subcells get positioned the one to the other when they are stacked in the barrel. The parallelism of the adjacent subcell and spacer is assuredly a critical parameter as it can tilt the entire subcell. The other parameter to take into account is the fit of the different subcells into the barrel: the element decenter is a function of the tolerances on the subcell OD and barrel ID and the nominal clearance.

When the subcells are passively stacked with relatively tight tolerances so that they just slide into the ID of the barrel, this can result in subcells’ centration of less than 10 µm. More precise control of the centration is possible with hand-matching of the mechanical parts to achieve tighter fits, or active alignment of the subcells after stacking into the barrel. However, this adds extra steps and complexity to the assembly process and depends on the required level of precision.

With this type of cell-mounted design, using precision modern centering techniques to align the lens elements within the subcells, an overall 10-15 µm placement accuracy can be achieved easily and consistently, which is suitable for most precision multielement lenses. By combining the stack-mounting arrangement with the potted construction, this assembly technique makes it possible to control and precisely predict the position of the lenses relative to each other for centering and separation, without demanding very precise edging. This makes it particularly effective for small production batches. It is however not a cost-effective solution for high volume production since the individual alignment of the lenses in the subcells is quite labor intensive.

Edge-mounting
In this type of “drop-in” cell-mounted construction, the lens element is not adjusted in its subcell. Instead it is radially positioned by the inside diameter of the subcell wall by tightly controlling the diameter clearance. The alignment of the element within the subcell thus depends on the lens centration and diameter fit, as previously discussed for the edge-mounted design (Figure 3). Tight tolerances on the subcell datum surfaces and barrel bore are in addition required to ensure precise axial and radial positioning of the subcells to one another.

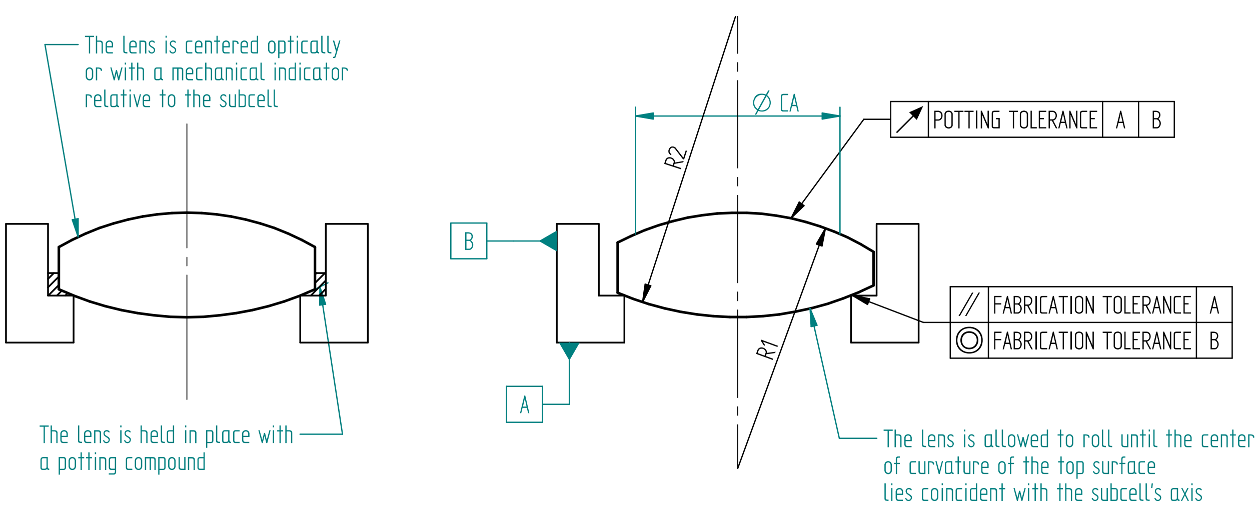


Figure 4 : Active element alignment. The lens element is actively centered within its subcell and potted in place. Lens wedge and diameter do not affect element placement accuracy.

This hybrid lens mounting technique has the advantage of avoiding problematic tolerance stack up by having airspaces and element tilts controlled by the precision machined subcells stacked on each other. Only one or two preselected airspaces are usually adjusted with shims to compensate for element thickness and radii tolerances. On the other hand, extremely precise edging of the lenses is needed together with micron level control on all metal parts in order to achieve placement accuracies in the 10 µm range or below. For this reason it is applicable only to high volume production of precision multielement lenses, where serial manufacturing and the use of dedicated tooling makes it possible to meet the required tolerances in a repeatable and cost effective process.

Mounted element centering

In this approach, instead of using active alignment during potting and or precise edging to get the lens element centered, it is the metal subcell itself that is turned or ground concentric. The lens is first fixed in place, bonded or clamped with other means, and its optical axis is determined. The subcell is then ground or machined on a turning lathe with respect to the optical axis of the lens (Figure 5). With the turning process, not only the outer surface of the subcell, but also the front and rear flange surfaces can be machined to adjust both vertex and flange distances. This makes it possible to align the mechanical axis of the mount to the optical axis of the lens element, and set the air gaps, without exceptionally tight tolerances on the cell features, lens centration and diameter.

With the ultra-precision turning machines currently available, using fully integrated metrology, cell-mounted lenses with axial placement and centration accuracy in the micrometer range can be produced with most common lens mount materials. The mounted lenses machined this way can then be simply stacked into one lens barrel. Taking into account the achievable machining tolerances and the stacking errors, this results in placement accuracies < 5 µm. Multielement lenses can thus be assembled in a precise and reproducible way without the need for further complex adjustments.

Moreover, at the difference of the previously described precision "drop-in" cell-mounted method, this technique is not only applicable to very high volume, standard products, but it is also optimal for the production of smaller and medium-sized series. However, there are some limitations beyond the higher investment costs. In particular, it can only be used for rotationally symmetrical cells and lenses and may require specific opto-mechanical designs (Figure 6). The selection of materials for the subcells is also generally limited to materials that can be diamond turned. Finally, the fact that the final machining of the subcells is done with the elements in place makes the process incompatible with applications requiring all materials to meet strict cleanliness standards, such as deep UV applications.

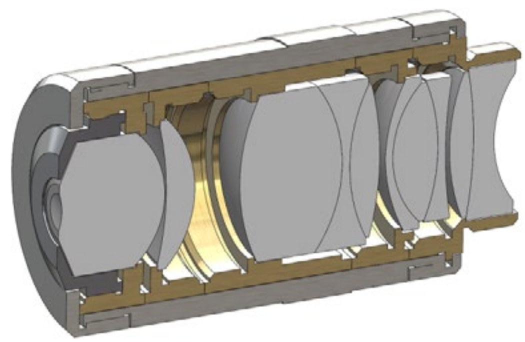


Figure 6 : Example of stacked-cell assembly using the mounted element centering method. The opto-mechanical configuration and subcells' design were specifically adapted to use CNC-controlled turning for the machining and alignment of the cell-mounted lenses.

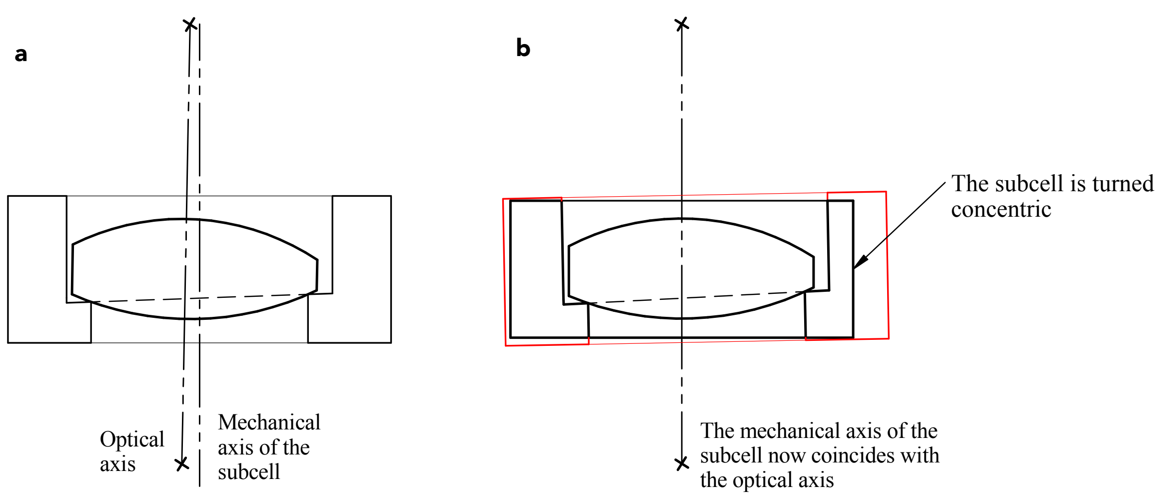


Figure 5: Mounted element centering a) the optical axis of the mounted lens is determined, b) the subcell is trimmed to final size with its outer diameter aligned parallel to the optical axis.

Melles Griot Exact Placement Lens Assembly Technology

To overcome the limitations of the drop-in assembly and conventional stack-mounting technique and to achieve the best positioning accuracy, Melles Griot has developed its own Exact Placement lens assembly technology. Based on barrel-less construction combined with ultra-precise active lens alignment in five degrees of freedom, it enables micron level placement accuracy of each optical element within the lens assembly. Moreover, this mounting method does not require extremely tight tolerances on all the dimensions of the parts. Only high precision is needed on the form tolerances of the metal subcells (i.e. parallelism, roundness, and flatness), while more liberal optical fabrication tolerances can be used for the optical elements. High performance multielement lenses can thus be assembled with near-perfect positioning in a highly predictable and repeatable process.

Ultra-precise lens alignment
At first each element is accurately positioned and bonded in place within its subcell using proprietary tooling and high-end metrology. At the difference with the commonly used potted assembly construction (Figure 4), the lens is freely positioned inside the subcell without resting on a lens seat. This makes it possible to achieve extremely precise alignment of both lens surfaces, as well as to adjust the axial position of the element (Figure 7). The attainable placement accuracy on the lower lens surface is no more limited by the precision with which the subcell internal features are manufactured.

Proprietary alignment stations with integrated measuring technology were developed to be able to adjust and monitor the relative positions of the subcell and element with the required accuracy and resolution. The alignment stations rely on air-bearing spindles coupled with both tactile and non-contact measurement systems to precisely track the positions of the optical surfaces of the element and the subcell simultaneously.

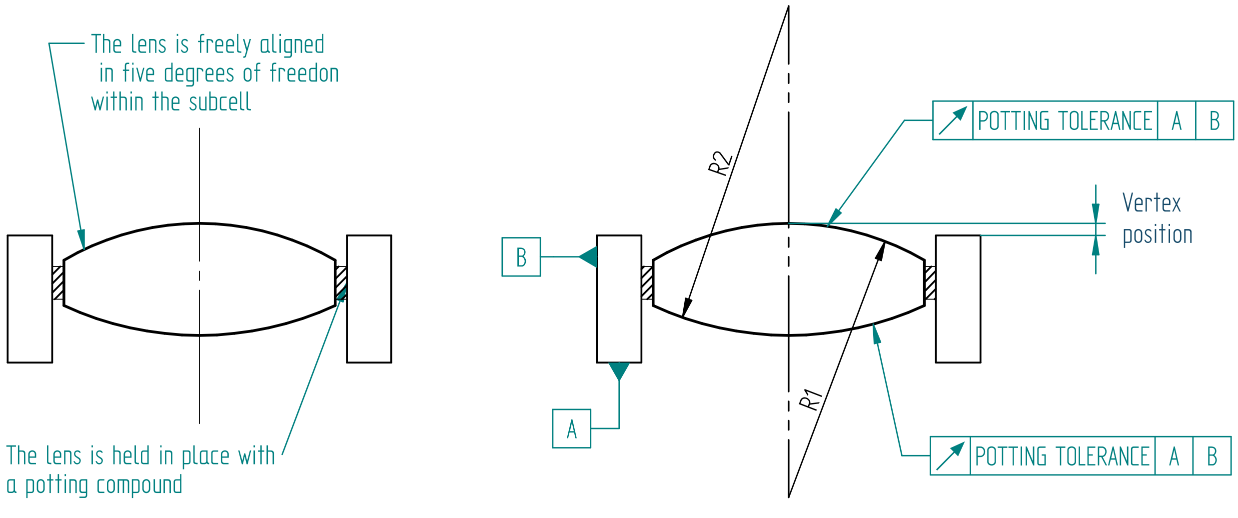


Figure 7: Gap potting with high precision active lens alignment. The element is freely positioned relative to the OD and one side of the subcell so that both centers of curvature are aligned. The flange distance is also precisely controlled. Lens wedge and diameter do not affect element placement accuracy. Only high precision is needed on the form tolerances of the subcell's reference surfaces (i.e. parallelism, roundness, and flatness).

With this assembly technology, mounted optical surfaces are routinely located to micron level accuracies, with all internal airspaces prescribed at the time of assembly typically controlled within 2 μm.

Table 1 shows, for comparison, the typical manufacturing tolerances for lens diameter and wedge. To make a high precision lens assembly, it is necessary to place tight tolerances (± 2 μm) on all the operations in both the optical and machine shop. This can significantly affect the cost and yield and is only appropriate to high volume production. Active optical alignment shortcuts the precision requirements on the lens shaping step and, at the same time, extends the achievable precision.

Another advantage of Exact Placement is the "gap" potting design that allows the free axial positioning of the lens element within the subcell during the assembly. This way the internal airspaces recomputed from the rebalance model can be directly and precisely adjusted.

The production of high-end optical assemblies with very demanding performances imposes stringent requirements not only on the relative positioning of the individual optical elements, which is the scope of this paper, but also on all optical tolerances. Therefore, in many cases, the final optical design needs to be modified based on the real glass data and as-built radii of curvature and thicknesses of the lenses. This helps relieve the extremely tight tolerance requirements and maximize system performance. Compensation can be done by reoptimizing the airspaces, which is usually an efficient balance to the aberrations, and can be easily implemented for small volume production. With Exact Placement, such airspace adjustments are integrated directly during the production build and controlled within 2 μm.

Barrel-less construction

The second innovative feature of this proprietary assembly technique is that the subcells themselves form the outer interface of the assembly, which eliminates the inherent centration inaccuracies when stacking the subcells inside the lens barrel (Figure 8). The barrel that goes around, if any, has no need for precision or stability; it just provides a means of interfacing with the whole system. Very high precision machining is only required for the outer features of the subcells, as this directly determines the radial and axial positioning of the lens elements. With in-house capabilities in metals fabrication, we ensure sub-micron level control on the parallelism and flatness of the subcells' plane mounting surfaces, using diamond turning to provide state-of-the-art accuracies for the critical geometries.

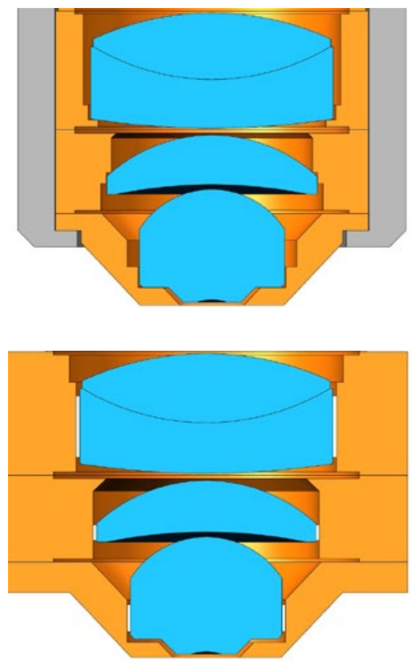


Figure 8 : Melles Griot Exact Placement with the barrel-less construction (bottom) versus the traditional cell-mounted construction (top).

Fabrication Tolerance:	Industry accuracies for individual lens elements				Limit extended through compen-sation with Exact Placement
	Commercial Grade	Precision Grade	High Precision	Manufacturing Limit	
Centration (edge thickness variation, mm)	0.05	0.015	0.005	0.003	0.0005
Diameter (mm)	+0/-0.10	+0/-0.025	+0/-0.005	+0/-0.003	+/-0.001

Table 1: Comparison between the production tolerances for lens centering and edging, and the extended limits that can be achieved through gap potting and active element alignment.

For such barrel-less construction, the subcells can be passively aligned utilizing the matched outer diameters of the cells and then locked in place, or the subcells can be individually aligned to achieve final centration accuracies to 1 µm (Figure 9).

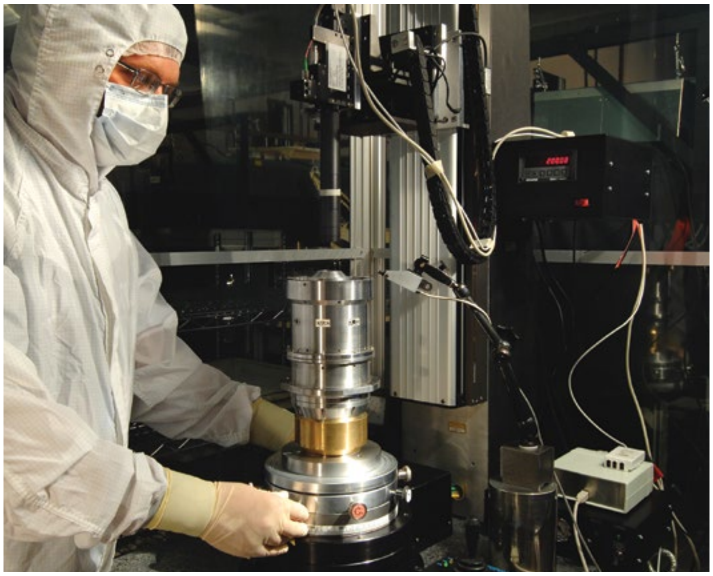


Figure 9 : Active alignment of the subcells during final assembly: non-contact verification of element centration is performed within the multielement lens assembly.

Stability and low stress mounting

As part of this new technology development, thorough investigations were required on the fixing and bonding process itself with special attention to the characteristics of the adhesive that is applied to the edge of the lens. Firstly, our process offers low shrinkage and high stability, which is essential for such sub-micron lens placement to make sure that the lens' position is not affected after curing. Secondly, it ensures that very low stress is being imparted to the lens through the mounting mechanics and the adhesive being used. Finite Element Analysis (FEA) together with interferometric testing were used to model and control the amount of distortion on the optical surfaces depending on the mounting configuration.

The requirements for surface irregularities have become more stringent in demanding optical systems, especially with the use of shorter wavelengths. In optical lithography, for example, lens element surface accuracies of better than $\lambda/50$ typically need to be maintained, with the optical system used in a vertical orientation.

Therefore, special attention must be paid to the mounting conditions, as well as on the self-weight distortion effect, so that the optical surfaces do not get significantly distorted. For such demanding optical assemblies, an imperfect lens seat, even slightly elliptical at the micron level, can have a detrimental effect on the performance.[3] Figure 10 shows the typical non symmetric distortion that can occur from two-point contact when an element is mounted against a hard seat. To this regard, one clear advantage of the Exact Placement design is that the lens element is not potted directly to a seat, but is instead "freely" bonded inside the subcell around its circumference. This gap potting approximates the full circular support condition as shown in Figure 11, yielding very low induced irregularities.

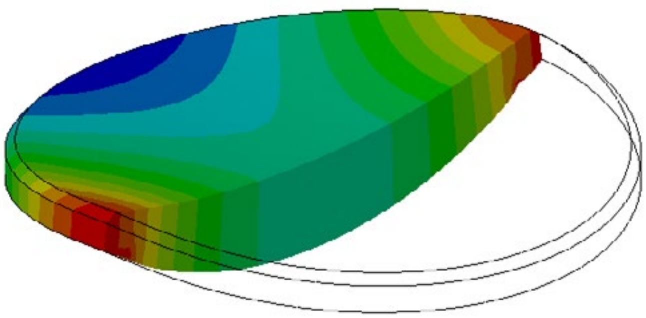


Figure 10 : FEA prediction of a meniscus lens resting in a subcell with primarily two-point contact. The upward facing concave surface exhibits a strong distortion with an astigmatic saddle shape.

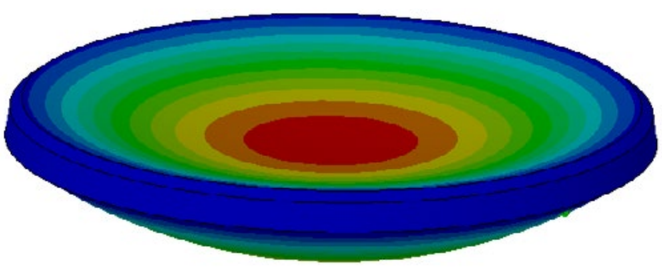


Figure 11 : FEA prediction of self-weight distortion of the same lens element resting on a perfectly circular seat. The resulting distortion is approximately seven times smaller.

A high level of flexibility

This lens assembly technology offers a high level of flexibility in term of system size and volume, and can be easily implemented to build various types of high performance lens assemblies for the entire DUV to NIR range. The alignment stations and lens mount designs are adaptable to a wide range of diameters and optical materials. We have gap potted so far elements from 6 mm to 6 inches, made optical glass, fused silica, calcium fluoride, magnesium fluoride or barium fluoride. There are also no limitations on the mount materials (like aluminum, steel or brass), provided they can be machined to the required form tolerances. Thanks to special low contamination bonding and assembly technologies, objectives have been produced by Melles Griot for use at laser wavelengths as low as 248 nm and broadband usage as low as 200 nm.

Figure 12 shows an example of a high performance objective built with the Exact Placement lens assembly technology. This infinity-corrected objective consisting of sixteen elements in ten groups has a focal length of 2 mm and a numerical aperture NA=0.95. It is designed for full spectral correction over a field of ±3°. The performance requirement is to remain diffraction-limited on-axis with a RMS wavefront error < $\lambda/20$, and to degrade to less than 0.1λ RMS at the full field over the whole wavelength range. In order to meet such a high level of imaging performance, very high precision is required on all the optical elements as well as their relative positioning.

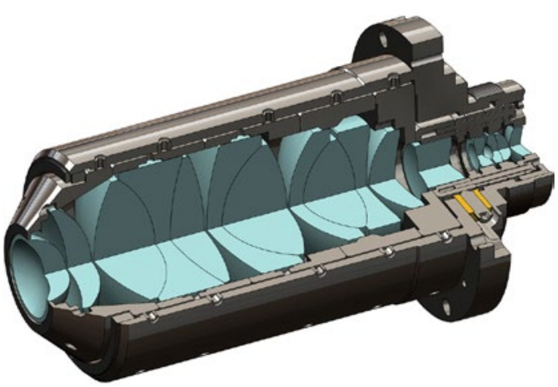


Figure 12 : 0.95 NA 100X broadband diffraction-limited objective for semiconductor inspection

Using the Exact Placement technology, we were able to mount the critical lens surfaces with a precision of better than 1 µm with respect to their ideal position. A rebalancing analysis was performed before the assembly to adjust the airspaces based on the measured element and melt data. In addition, a pusher for coma was included and adjusted dynamically by measuring the wavefront at the working wavelength with a Twyman-Green interferometer.

Conclusion

We have introduced the Exact Placement assembly technology developed and practiced by Melles Griot, and how it makes it possible to build multielement lens assemblies where each optical element is positioned to micron level accuracy, pushing them to a new level of performance.

This key enabling proprietary technology shows the engineering excellence that is at the core of the Melles Griot advantage. Through our innovation, experience and unique set of technical competencies, we have developed an ultra-precise and highly repeatable lens alignment solution, overcoming the manufacturing limitations for the production of very high performance optical systems. Coupled with full design and engineering capabilities, precision manufacturing and integrated metrology, it enables us to produce optical systems with outstanding and consistent performance throughout the product's lifetime.

Melles Griot has continued to invest in new technology with next generation alignment stations being developed to make use of advanced automation platforms to facilitate automated positioning operations to be used throughout the assembly process. These advances provide greater process efficiency and greater process repeatability to allow for quick scaling to meet increases in demand. These capabilities uniquely position Melles Griot to provide the highest performance optical solutions for the demanding semiconductor and life science applications.

This paper has also outlined the most common lens assembly techniques, with the difference they offer in terms of element placement accuracy and production volume capabilities (Figure 13). It has reviewed the specific manufacturing tolerances that need to be considered to control the relative positioning of the optical elements within the assembled system, how they depend on the mounting arrangement and lens centering method (passive versus active).

While the requirements can vary from several dozens of microns down to tolerances in the micron range or lower for the most demanding systems, all lens designs necessitate more or less precise positioning of the optical elements within the assembly in order to achieve the desired performance. The opto-mechanical design, with the choice of the optimum lens assembly technique, is a complex task and requires a comprehensive understanding of the various mounting methods, production capabilities, and metrology tools.

Once the mechanical concept has been established, rigorous analysis is essential to take into account and simulate all the inaccuracies that can impact the centration, axial placement and surface accuracy of the optical elements in the as-built system. This ensures that the assembly process is reliable and predictable rather than relying on "gut feel" or "trial and error" and that the optical system will work the first time.

At Melles Griot we know that each system is unique, and we employ different strategies for different systems. From simple drop-in assemblies to highly-compensated objectives for wafer inspection and other challenging metrology or life science applications, we can work with you to deliver a solution that meets all requirements for performance, cost, and delivery.

Our approach is to work with the customer in a solution-oriented partnership, with close collaboration through all phases of the development cycle, from concept through production support. Every application is different, and the range of opto-mechanical solutions available is wide, but success comes down to doing adequate design validation and trade-off analysis up front while the optical system is still being conceived. Using our collaborative approach, in-depth development and production experience, and application specific expertise, we optimize all aspects of the system design and always keep an eye toward manufacturability and production. Simulation of the fully integrated as-built opto-mechanical systems and extensive system level testing ensure that products will meet all expectations.

With in-house capabilities in metals fabrication, element fabrication, coating, diamond turning, high precision assembly along with extensive optical metrology—combined with full engineering expertise in optical, mechanical and system design—Melles Griot takes on projects at any level of design maturity, from concept, to prototype, to full series production. We would be pleased to support you in creating a high value solution optimized for your application.

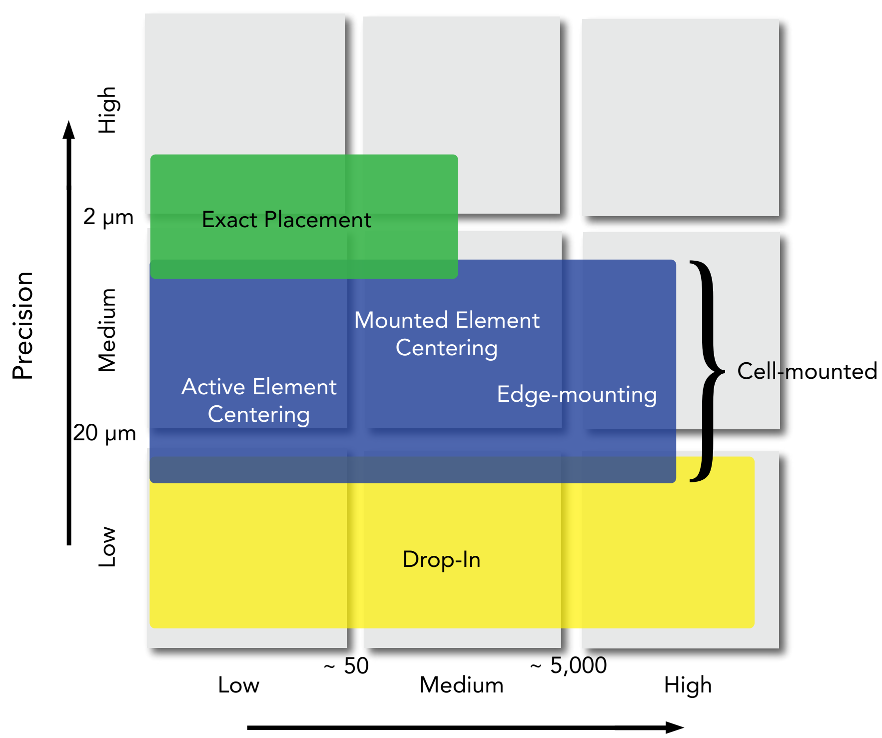


Figure 13: Both the positioning precision and the volume requirements need to be taken into account to deliver an opto-mechanical solution fully optimized for performance, manufacturability and cost.

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Enabling micron level mounting accuracy
Melles Griot Exact Placement™ lens assembly technology

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