Material Properties and Selection

MATERIALS AND PROPERTIES

The design of robust, accurate, and stable opto-mechanical components begins with the proper selection of construction materials. Factors such as cost, machinability, durability, corrosion resistance, hardness, thermal expansion, and weight must all be considered. Most CVI Melles Griot opto-mechanical component designs use aluminum, steel, and brass because of their overall desirable properties. Specialty materials are used in certain circumstances. For example, if a thermally stable Fabry-Perot interferometer is desired, then a material with a small thermal expansion coefficient like Invar™, quartz, or a ceramic should be used to hold optical elements. The cost increase from material selection must be weighed against specification improvement for the particular application.

Aluminum

Aluminum is the most commonly used opto-mechanical hardware material. It is economical, easy to machine and lightweight; it also has a good stiffness-to-weight ratio, and low creep. Finished products are soft but can be anodized to harden surfaces for improved wear and durability, and surfaces can be blackened for low reflectivity.

Aluminum expands or contracts with changes in temperature, making it less desirable for components that require long-term stability. The high coefficient of thermal expansion for aluminum is partially offset by a high thermal conductivity. By quickly reducing thermal gradients within the component, large conductivity mitigates relative distortions caused by temperature-induced differences in expansion. This quality is measured by a low relative distortion figure (thermal expansion coefficient/thermal conductivity). Furthermore, aluminum's large thermal heat capacity buffers local thermal perturbations thereby minimizing temperture changes and resultant dimensional fluctuations.

Aluminum is the material of choice for optical mounts such as lens holders, kinematic mirror mounts, and prism tables. One drawback to using aluminum is the relatively high friction between a moving steel adjustment screw and the aluminum body. High levels of friction can lead to excessive thread wear over time and a reduction in adjustment screw feel and fit. Good lubricants can be used to reduce friction and extend the component's lifetime. For an OEM application requiring only occasional adjustment, this is an excellent choice. For heavy use, or where a small increase in expense can be tolerated, the preferred approach is to install a brass bushing into the aluminum body. The brass insert reduces baseline friction (no lubrication needed) and allows closer tolerances to improve fit and feel. Excellent results for the entire series of kinematic mounts have been achieved by using brass inserts in aluminum bodies.

Steel

Although it is more expensive to machine than aluminum or brass, steel has a better stiffness value and a lower thermal expansion coefficient. While the stiffness-to-weight ratio is very similar, the relative distortion figure is worse because of the low thermal conductivity of steel. Steel is commonly used in positioning stages to minimize temperature-induced errors and to hold tight dimensional specifications for varying loads.

A unique application of steel is found in high-precision flexure mounts. These mounts are fabricated from a single piece of hardened spring steel which minimizes differential thermal expansion and assembly wear problems. Steel is particularly useful for making flexures and springs because of it high yield strength. Stainless steel is also a popular material for posts and pillars because of its relatively high stiffness and corrosion resistance. CVI Melles Griot damped StableRods™, fabricated from nickel-plated steel tubing with a patented vibration-reducing core filler, is an example of material selection designed to solve an opto-mechanical problem.

Brass

The material of choice for most 18-th and 19-th century instrument makers, brass is the traditional opto-mechanical material. Although its excellent machinability and good surface finish keep it a contender, brass is increasingly being replaced by aluminum and steel because of its relatively low stiffness-to-weight ratio. Some hybrid components are made largely of aluminum or steel, but brass is used selectively for precision bushings or adjustment screw threads owing to its anti-seizing properties. CVI Melles Griot still provides some brass mounts in which economic considerations do not warrant a change to hybrids. For example, CVI Melles Griot flexure mounts continue to have brass bodies with stainless steel adjustment screws inserted directly into the body.

THERMAL EXPANSION

Different materials respond to changes in temperature with varying degrees of expansion. Of the material used in making opto-mechanical components, steel has one of the lowest coefficients of thermal expansion. It is an excellent choice for positioning applications in which thermal stability is needed at a fair price. The challenges of today's research leads to increasing demands for long-term stability, extreme accuracy, and many degrees of freedom. Advancements in submicron structures on integrated chips, single-mode fiber pigtailing, and super-resolution microscopy demand an intelligent approach to the many types of materials that must be combined into today's positioning systems.

A solid bar of stainless steel, 10 mm long, will change in length about 100 nm for every degree change in temperature (Celsius).This change in length is hundreds of atomic diameters. If the steel is used to position an optical component, it may shift the component away from the necessary location. Thus, the designer of a precision component or instrument must engineer a method to compensate for or eliminate thermally induced strain through design and material selection. This design process is known as athermalization.

MATERIAL FINISHES

In many cases, material finish is just as important as the material itself. Proper finishing provides protection, increases durability, and improves appearance. Most opto-mechanical components are black anodized or otherwise finished to reduce unwanted and potentially hazardous spectral reflections.

Anodizing, an electrochemical conversion coating, is the preferred finish for aluminum since it also protects and hardens the material, increasing scratch and wear resistance. Anodized aluminum, which is slightly porous, creates a matte, rather than smooth, texture, which diffuses light and minimizes direct reflections. This is particularly important when high-energy lasers, which might cause eye damage, are used. The porousness of an anodized finish, however, makes it unsuitable for vacuum applications beyond 1×10^{-6} Torr.

The finish used on steel depends on the application. Steel parts can be nickel plated for corrosion resistance and durability. Steel used for translation stages is coated with black chrome to minimize reflections and corrosion. Because stainless steel is inherently corrosion free and durable, it is usually passivated and brushed to minimize specular reflections. Passivation is a chemical surface treatment which removes foreign particles introduced by machining or heat-treating. Brass is usually coated electrophoretic black, painted, or left unfinished owing to its ability to resist corrosion.

SCREW FASTENERS

Socket-head cap screws are used almost exclusively to assemble various types of opto-mechanical components. The hexagonal key slot in the head of the screw allows the user to impart a significant amount of tightening torque compared to cross-head or slotted-head screws. The most common sizes of socket-head fasteners used with opto-mehcanical components are ¼-20, 8-32, and 6-32. In the metric system, the most common are M6, M4, M3, and M2. Details of these types of screws are shown in the following tables. One little known fact about socket-head cap screws is that the thread diameter is the same size as the head height. This is done to provide a means for easily determining the size of the screw thread if the screw has already been installed.

Socket-head cap screws

Comparison of Material Properties

	Aluminum	Brass	Stainless Steel
Type	6061-T6	Free-cutting	303
Density (lb/in.^{3})	0.10	0.31	0.28
Stiffness (1×10^6 lb/in.^{2})	10	14	28
Yield Strength (1×10^3 lb/in.^{2})	40	52	75
Coefficient of Thermal Expansion (1×10^{-3} in./in./F)	12	11	6
Typical Finish	Anodize	Paint, black chrome, oxide	Passivation
Advantages	Light weight, high strength-to-weight ratio	Anti-seizing properties	Stiffness, corrosion resistance

Socket-head Cap Screw—Inch

	Thread Diameter (in.)	Thread Pitch (in.)	Head Height (in.)	Head Diameter (in.)	Allen Key Size (in.)
6-32	0.138	.03 (32 TPI)	0.138	0.226	7/64
8-32	0.164	.03 (32 TPI)	0.164	0.270	9/64
1/4-20	0.250	.05 (20 TPI)	0.250	0.375	3/16

Socket-head Cap Screw—Metric

	Thread Diameter (mm)	Thread Pitch (mm)	Head Height (mm)	Head Diameter (mm)	Allen Key Size (mm)
M2	2	0.4	2	3.8	1.5
M3	3	0.5	3	5.5	2.5
M4	4	0.7	4	7.0	3.0
M6	6	1.0	6	10.0	5.0