OPTEC LASEA GROUP

Lifetime of Optics in Excimer Laser Systems

General

It is notoriously difficult to estimate optics lifetime in excimer laser-based systems, since experience shows that operating environment is often an important factor. This note aims to highlight the different things that can go wrong rather than provide a guarantee in any particular case. Optec has many hundreds of systems in the field over 30 years, and cases of systematic premature optics failure are rare.

Only two materials are considered for operation at 248nm & 193nm, **UV grade fused silica**, generally termed **UVFS,** and UV grade Calcium Fluoride CaF2. Many Optec systems use our 3e lens where outer elements are CaF2, centre element UVFS. Those lenses have been a key component of Optec systems since 1997; we know of optics still working fine after 20+ years, but some rare cases where optics have failed in much shorter times

Bulk effects

There are many grades of fused silica, not all of which are recommended for ultraviolet use. For UVFS, it is known that prolonged exposure to excimer radiation results in a number of bulk effects - **densification/compaction**, creation of **dangling bonds** - which combine to reduce transmission. These effects can cause **fluorescence**, whose intensity & colour depend on trace impurities at the ppm level. Some suppliers specify 'laser grade' whilst others specify different grades of UVFS recommended specifically for KrF & ArF.

These bulk effects which lead to loss of transmission are generally lumped together under the category of **'Laser Durability'**. We can quote an example at low fluence, (<15mJ/cm2, 30Hz), where UVFS lenses have lifetimes in excess of 2Bn shots without significant losses. There is no sharp onset of transmission loss, instead rising significantly as a function of incident energy density (e.d.) above about 0.1J/cm2. In the end, as lens transmission decreases, it simply makes good economic operating sense to replace worn optics rather than run the laser harder to compensate!

Compared to UVFS, CaF2 generally has better laser durability, we have one example of a CaF2 lens exposed to 90mJ/cm2, 150-170Hz, lifetime >2Bn shots. However, like all ionic crystals, it is much more difficult to polish without introducing **sub-surface damage**. This damage not only affects lifetime due to formation of **colour centres**, it also affects coating resistance. Laser durability of CaF2 & **ssd** have been the subject of specialist studies because of its importance in lithography.

We have to rely on our suppliers to select the appropriate quality of raw materials. Both of Optec's principal suppliers are highly reputable & have supplied excellent lenses to Optec in the past. We have also encountered occasional problems with both, and attributing blame can be tricky when for e.g. a 3rd party coater is involved. There are several impediments to having more suppliers:-

a) Not all can polish CaF2 successfully

b) Since there is no agreed DIN standard for tools & test glasses, changing a supplier means redesigning the lens;

c) Acceptable bulk pricing is only obtained in quantity, so having more than 2 suppliers is not a realistic proposition.

Surface Effects

There is a loss of about **4% per surface** due to the refractive index alone, plus loss due to scattering, since even the best polished surfaces remain somewhat rough at the scale of UV wavelength. In order to minimize these losses, anti-reflective **AR coatings** are universally applied to lens surfaces, and the usual mode of abrupt failure of an optical component is destruction of this AR layer. Suppliers usually quote a **'damage threshold'** on the order of J/cm2, but this threshold is usually determined experimentally using a relatively low number of shots. Our experience is that coating lifetime in the absence of contamination is arbitrarily long at e.d. <0.1J/cm2, although we have many systems where isolated components are exposed to significantly higher fluence without suffering any apparent performance degradation.

Coatings on CaF2 are difficult to apply correctly and have to be applied to substrates at elevated temperatures, whilst e-beam techniques can generate a pink tint of the optics! Some lens manufacturers have their own coating facilities, others are obliged to subcontract, or more commonly Optec organizes coating. Again, 'errare humanum est' ; at times we have experience difficulties with ALL our coating suppliers bar one U.S. supplier that seemed highly promising, but which unfortunately & definitively ceased its business operations because of COVID!

In general, correctly made optics should be able to resist the fluence in a correctly designed system for several 100M shots when used in a clean environment (see section on contamination); it is difficult to be precise but in the absence of other deleterious effects we generally consider 200M shots as a typical minimum useful lifetime; Optec has many cases of optics with significantly longer lifetimes.

Contamination

Contamination is all around us, for obvious reasons generally affects more seriously the outer surfaces of a compound lens, i.e. those directly exposed to the atmosphere, and indeed if damage is only seen on external surfaces then contamination should logically be the first suspect.

As every housewife knows, **dust** is always present to some degree and may need to be removed periodically. Best is a soft brush with blower; users should beware of aerosol type dust removers which can add contaminant via the propellant.

A dust particle irradiated on the surface can burn in situ, leaving a mark on the coating which will absorb UV, and may lead to local destruction of the coating; either will cause a tiny drop in transmission; the cumulative effect from large numbers of such localized events can be significant.

In humid environments like Japan**, fungal growth** can be an issue, and can also affect internal components since spores are microscopic.

Insects might be present; Optec's founder was once stung by a wasp in a clean room!

Ejecta from the process can be a problem, when in the form of particles this mostly affects the last surface closest to the target. If ejecta are small enough to become more or less permanently airborne they then join the many other both naturally occurring & manmade **aerosol particles** which have a major effect on Earth's climate, since they serve as nucleation sites for cloud formation, and as the CERN CLOUD experiment has demonstrated, the degree to which they do that also depends on both solar UV and cosmic rays.

Of particular concern are **airborne hydrocarbons.** Everyone know that a mechanical workshop smells of machining oil, but for e.g. oil vapour is present in most compressed air lines, and in the vicinity of most vacuum pumps. Virtually any polymer can be a source, for e.g. CLOUD found that Viton seals outgas heavily unless subjected to a baking cycle, and Optec has experienced cases where optics became contaminated by pure bottled nitrogen supplied through the familiar blue plastic tubing, and another because PI spin coating was being performed in the same clean room. We also know of cases where optics were degraded due to scattered radiation on paintwork or coloured Al anodization, and most of us are familiar with the 'hot electronics' smell, for e.g. an overheating motor. When exposed to 193nm radiation, such molecules are 'cracked' to leave a thin graphite deposit which is impossible to remove.

Human beings are a ready source of such contaminants, perfume, nail varnish, hairspray, deodorant or just plain old body smell; if the odour is detected, then the contaminant is present, and may well be so at lower concentrations even if there is no obvious odour.

The way in which airborne contaminants interact with the surface will depend on UV fluence but also on the nature of the surface, since the local chemistry is different.

Since in most cases Optec does not control the environment in which the machine is operated we in general cannot supply a blanket warranty which covers ALL causes of optics failure.

Protection

To some extent one can protect surfaces against contamination.

Windows can be used to place the optics in a sealed environment. This adds two surfaces, inherently lowering overall transmission, and displaces the problem rather than removing it, though one hopes that the deposit will now be on a lower cost replaceable component. There is a downside, in that there is now a small confined space between lens outer surface & window; this carries its own risk in that if any contaminants do get into that space, they now cannot get away, so such windows can aggravate rather than solve the problem.

The **Optec debris control nozzle**, normally intended for use with He, has two functions;- a) **to reduce redeposit** allowing the ejecta to get further away from the surface before thermalizing b) **to protect the last lens surface** by establishing a gas flow which sweeps contaminants out of the nozzle before they can reach the lens surface by diffusion. The nozzle does have to be correctly used to work efficiently; for e.g. when used with no gas flow, the nozzle can make things worse, since some contaminants will enter the inner nozzle and are then guided to the last lens surface with no means of escape.

No nozzle is 100% efficient at removing all process fumes which can then escape into the internal machine volume and affect all optics as airborne contaminants.

Optec has one application where the IPEX 248nm lasers run at close to 170Hz 24/7 for weeks at a time, the key Optec process lenses (all UVFS in that case) are protected from possible ejecta and also the aggressive local atmosphere of MEP by a simple nozzle directing a flow of filtered air away from the final window surface; that window has to be cleaned regularly due to surface contamination arising from that filtered air.