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Contamination of CO_2 laser optics

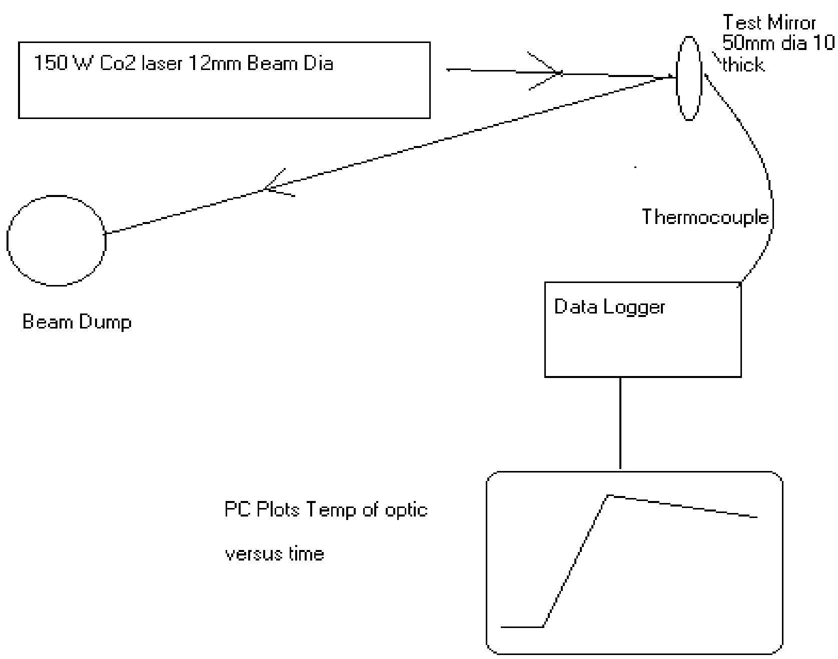
Introduction There has been much work showing that lenses and mirrors specified for CO2 lasers are capable of working at power levels far in excess of those found in a typical industrial laser. In fact a safety factor of ten or twenty times is common. The conditions leading to the failure of an optic in industrial lasers are invariably external, resulting from the operating environment, sadly beyond the control of the optics manufacturer.

There are of course several laser damage mechanisms, more than 500 papers on the subject have been presented at the Laser Damage Conference held in Colorado.

Although inter-related, two factors are common, 1) mechanical damage introduced by high velocity debris, or improper mounting, and 2) high absorption. One other factor, not considered here, is chemical degradation of the optic caused by UV radiation in the laser cavity, and highly reactive chemical species generated in the discharge.

Of the many failed optics we have examined, all have one feature, high absorption. This may have been caused by mechanical damage, or resulted in mechanical damage; either way absorption is a critical feature in the performance and longevity of an optic.

Experimental Equipment We have adapted our calorimeter,(normally used in quality control), to measure the absorption of a mirror deliberately contaminated with various materials found in a typical laser cutting environment.



The rate of heating of the mirror is measured by a precision thermocouple attached to the mirror. Knowing the heat capacity and mass of the mirror allows the rate of heating to be converted to the amount of the beam absorbed. Traditionally absorption is expressed as a percentage, but units of parts per thousand can give a better idea of scale, 0.1% = 1 part per thousand, 0.5% = 5 parts per thousand, etc.

Background Research Some time was spent searching computerised data bases of infra red absorption spectra. Millions of chemicals have had their absorption in the infra red catalogued, and it is possible to search for absorbing species at a specific wavelength, in this case 10.6 microns. Sadly the wavelength region around 10.6 microns is one where many chemicals weakly absorb and no one species could be said to be a uniquely strong absorber. One conclusion was that structures containing silicon and oxygen bonds could well be strong absorbers of CO2 laser beams. A feature of these databases is the material tested is carefully processed to ensure it's physical state, (powder, solution, liquid), has no influence on the absorption, a luxury not found in the industrial environment.

Test Conditions A gold coated copper mirror was used as the test optic. The rationale being that the gold coating is very damage resistant, is chemically inert, and is easily cleaned after testing.

A variety of contaminants thought to be common in an industrial cutting environment were applied to the mirror face. It was hard to be scientific in the application of the contaminants: liquids were typically wiped across the face, solids "dusted" on the mirror face. The actual amount of contaminant applied was attempted to be roughly equal each time. The amount of contamination applied was substantially greater than would occur during realistic use. Just one mirror was used, it being cleaned after each test, and checked to see it's absorption had returned to the low level measured when new.

Interpreting Absorption Results The level of increased absorption needed to render an optic non functioning is surprisingly low.

For a lens or output window absorbing 2 parts per thousand (0.2%) when new, an increase to just 4 or 5 parts per thousand can severely reduce cutting performance.

For a copper mirror absorbing 10 parts per thousand (1%) when new, an increase to 30 or 40 parts per thousand could cause problems.

Each contaminated mirror was irradiated with the 150 Watt beam for around a minute, surprisingly the heating rate, and therefore absorption was very constant during irradiation. It was expected to see some variation as the contamination evaporated or burnt off, or perhaps as absorption varied with temperature.

CONTAMINATION DESCRIPTION	% ABSORPTION	MIRROR TEMP AFTER 60 SECONDS Deg C
BRAND NEW GOLD MIRROR	1%	21
LITHIUM GREASE	16%	44
EP 80 GEAR OIL	7%	31
DOW HEAT SINK COMPOUND	41%	80
WASHING UP LIQUID	37%	72
ZINC SELENIDE DUST	2%	22
FUMES FROM BURNT PVC	1%	21
FUMES FROM BURNT RUBBER	8%	32
SALIVA	1%	21
JEWELLERS ROUGE (IRON SULPHATE)	30%	63
FINE ABRASIVE (ALUMINIUM OXIDE)	43%	80
FINE ASH	23%	53
SILICONE ADHESIVE SEALENT	31%	66
"WINDOLENE"	21%	52
COPPER WIRE WOUND ACROSS FACE	2%	22
MIRROR AFTER 13 TESTS AND 13 CLEANINGS	1%	21

Discussion of the results The large variation in the individual absorption values measured is not surprising. We have seen many examples of heavily contaminated optics working well, and what appear clean optics that are strongly absorbing. For example the mirror held in the smoke from burning PVC was badly fogged but measured near zero increase in absorption. Conversely we know output windows mounted with silicone sealent will destruct if just a few flecks of sealent are on the optic.

The physical state of the contaminant seems not to be a factor. ZnSe, known to be a low absorber as a bulk material, is also a low absorber when a finely ground powder. The mirrors fogged by smoke from burning PVC and rubber were considerably different in absorption, despite similar appearance to the eye. It appears the absorption is determined by the chemical nature of the contaminant rather than it's physical state eg dust, liquid, thin film.

There is support for the prediction that silicon/oxygen compounds are strong absorbers, heatsink compound, silicone sealent, and ash being rich in materials like this. Dust samples collected from the air as part of pollution studies contains typically 25% by weight of these silicon/oxygen materials.

Finally to replicate the effect of embedded metal, the mirror had a grid of copper wire wound across the face. Absorption was low, copper being highly reflective. This is consistent with mirrors we have seen covered in metal spatter that continue to work.

Conclusions The results are consistent with observations we have made on used optics over many years. It seems that the absorption of a particular material is related to it's chemical structure, there is no evidence to presume liquids are worse than say particulates or condensed smokes. The appearance to the eye is no guide as to the level of absorption of the optic.

Materials containing silicon and oxygen were predicted to be strong absorbers, and there was some evidence for that. Heatsink compound and silicone rubber are used in mounting optics, these materials need great care in keeping residues away from optics.

Cleaning materials occasionally used, such as rouge, fine aluminium oxide, and detergents are strongly absorbing. There is really no need for these materials to be used. Using organic solvents and the techniques explained in a previous AILU article allowed the heavily contaminated test mirror to be cleaned 13 times with no loss of performance.

We are happy to investigate other materials that laser users may consider a problem, specific brands of lubricants for example, or other materials that find common use and that we are unaware of.

Eventually we would like to draw up a list of materials known to be strong absorbers so that in time, they could be replaced by equally functional products that are less absorbing.