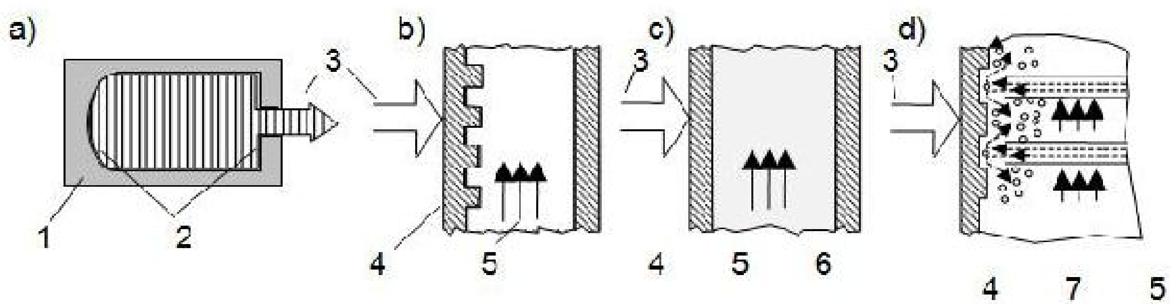
Mirror for powerful laser

Resonator, consisting minimally of two optical mirrors, has been an integral part of most lasers. Through one of them, e.g. half-transparent one, radiation is lead out. The first generator mirrors were traditional -quartz discs with silver covering. But in recent years, power of lasers has grown by hundred, thousand and perhaps million times. A problem of creating mirrors, being able to work under the influence of powerful radiation appeared. This problem became one of central ones in improving powerful lasers.

A mirror even with very good optical surface doesn't fully reflect radiation falling on it, about 1% of it is absorbed and turned into heat. In powerful lasers this 1% is enough for thermo tensions to appear in the mirror. They distort geometric form of the reflecting surface disabling fine focusing (and hence desired concentration) of rays. In fact thermo deformations lead to break of phase; laser stops being a laser.



Elaboration of a mirror for a powerful laser

1 - resonator, 2 – metal mirrors, 3 – current of laser radiation, 4 – mirror surface, 5 – heat carrier, 6 - CPM, 7 - vapor.

a) resonator assembly unit, radiation is removed through the hole in the mirror, b) mirror with channel structure, current of heat carrier cools ribbed wall, c) mirror is cooled by heat carrier, coming through the pored material, d) water is pumped to reflecting surface by canals, gets boiled, mixture of liquid and vapor is lead to transverse current of heat-carrying, is cooled and is gotten out of mirror.

What is the limit for these troublesome thermo deformations? It shouldn't exceed 5-10% of the length of the wave of laser radiation. For CO_2 laser with length of the wave 10.6 micrometers falling in infrared band, distortions shouldn't exceed 1micrometre. If one takes such a mirror in hands, in few seconds deformations of optical surface will exceed the permissible magnitude because of the unequal warmth provided by hand. But this is temporary 'spoiling'- these are elastically reversible deformations. Beside elastic deformations plastic deformation can take place at bigger powers, and then the mirror area would be destructed permanently.
Translating problem as power challenge, it was required to produce mirrors that withstood prolonged tensions up to several kilowatts to $1cm^2$ of their surface. This power can be compared with that radiated by the sun from its surface. It means that if we put our mirror on the sun, its form shouldn't deform for more than a micron. Indeed a challenge!

Physicists considered it like this: quartz badly conducts heat, thus it should be changed for metal. For fully reflecting mirror it is okay. But for half-transparent mirror, they got stuck. They finally decided to use metal for this purpose also, but with a modification. A hole in the centre of the disc let some radiation pass through. Resonator appeared like chamber with aperture at one end. Figure 39 traces entire evolution of this technical system.

Metal discs removed heat well but had disadvantages: high coefficient of thermal expansion altered their size and form at change of optical loading; low firmness so it's difficult to polish.

Interlude: change of quartz for metal as technical solution seemed wild, strange; it just shocked opticians-specialists in producing mirrors. Little did they know about queerer surprises ahead?

Searching for a better composition began: metals, alloys. Almost all alloys available for mass usage were tried. As a result of such searching, increase of the limit of optical working capacity was managed by 10 times. Fight didn't end here.

Requirement of power of light went up. Laser's functional performance (FP) or sum of Most Useful Functions (MUF) executed by laser had risen. With it grew thermo loadings. Metal thermo conductivity couldn't provide dissipation of this powerful heat current. How was this problem solved?

Cooling is required, a forced distraction of heat by some moving liquid. Greater is difference of temperature between heated body (mirror) and cooling body (liquid) faster is shed of heat. Calculations showed that the problem would have been solved if magnitude of this difference was more than 1000C. It means that mirror should have a temperature 1000C above liquid. But such temperature is impossible for metal mirror as one cannot provide good quality of optical surface at such temperature. Contradiction: one requires high temperature for good heat distraction and for the stability of geometric form and other optical characteristics of the mirror one requires low temperatures.

Site specialization started with attention focused on back of mirror – it was this part of mirror which exchanged energy with running liquid. Smooth surface on the back of the mirror doesn't provide the required intensity of heat distraction. In order to enlarge the surface of heat transmission they undercut trenches were undercut along which water was led along. To fasten heat transmission, walls of canals were thinned and velocity of water increased. This reached a limit too. Walls of canals trembled and deformed under water pulsation. This contradiction was resolved by making transition to capillary porous material, popularly known CPM. Advantages of CPM: vast surface of heat transfer, good intermixing of cooling liquid which moves in the capillaries, high mechanical tightness of matrix-skeleton safely carries the mirror surface and saves its geometry. CPM is applied with a covering and polished to turn it in a mirror. Thickness of the covering is 100-500 micrometers, not more, otherwise it would retain heat.

Possible way of application is via chemical transportation reaction from gas phase, i.e. collecting at atomic level. And it means that the surface grown would primarily be smooth - humps and valleys not more than 0.1micrometre. Post-processing viz. polishing, roughness remains only a thousandth part of micron.

But again man is discontented. Laser becomes powerful, same old increase of MUF. With it, temperature rises. So speed of heat carrier motion is increased. How? Liquid molecules now instead of 'floating' must 'fly'. How to do this? Contradiction: for good heat removal the agent should be presented in liquid state (high thermal capacity) and for quick exchange of heat (inflow-outflow at high speed) -by gas. Solution is rendered by use of 'resolution of physical contradiction by separation under condition'. Phase transition. At heat removal, it should be liquid, and at elimination – gas (vapor). Liquid should get boiled into vapor and latter should impetuously get away from the heating zone. To improve boiling, it was done under pressure of air. Good part is that air molecules don't interfere with vapor particles movement. Heat pipe! Yes. As liquid they used melted metal, which took quite big portions of heat with it at vaporization. Vapor speed reached sound speed but this was the last border.

Till now, on such mirrors great intensity of thermal dissipation was achieved, up to several tens of kilowatts on 1cm2, actually it reached 100kw/cm2.And then? Increase of MUF is a non-stopping process. How can one withdraw power of 1000kw/cm2? Or say, 10000kw/cm2?

At such power the thickness of the wall should be vanishingly small - 1 micrometer or even 0.001 micrometer, or say 1 nanometer, i.e. there shouldn't be any wall at all. And the mirror itself, of whatever substance it is made of on Earth, will disappear into gas or plasma at 10,000C. So there is no mirror, but the function should be fulfilled. We are reminded of treatment of IFR earlier in book. The field (laser ray, electromagnetic radiation) should produce a mirror for itself. This mirror's surface made of liquid or gas has constantly renovated surface. Renovation is done by laser itself. Another physical limit, after sound speed, is more fundamental, viz. speed of light. Let heat be withdrawn at such speed by Infra Red radiation? Laser power can increase to several times. Story of Technical System development continues.