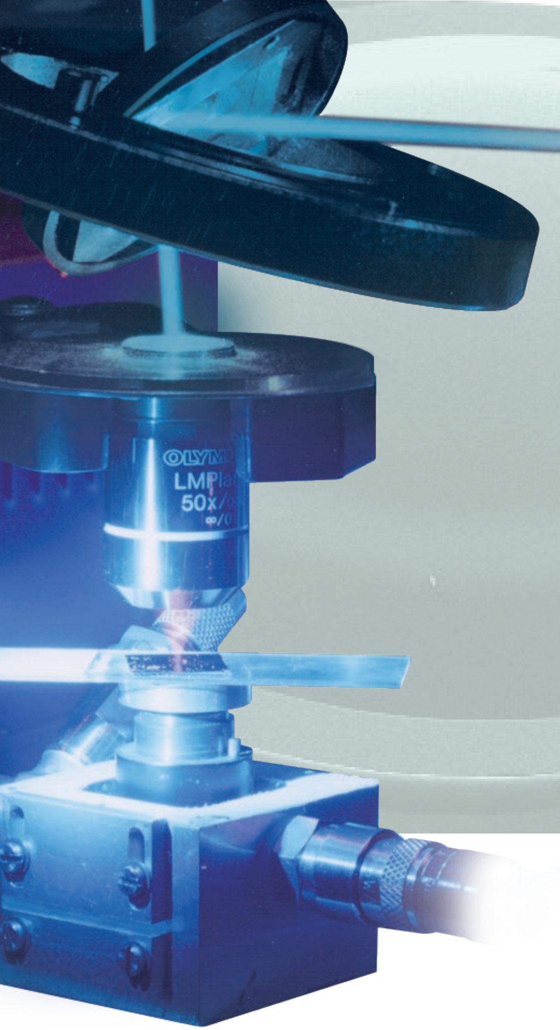

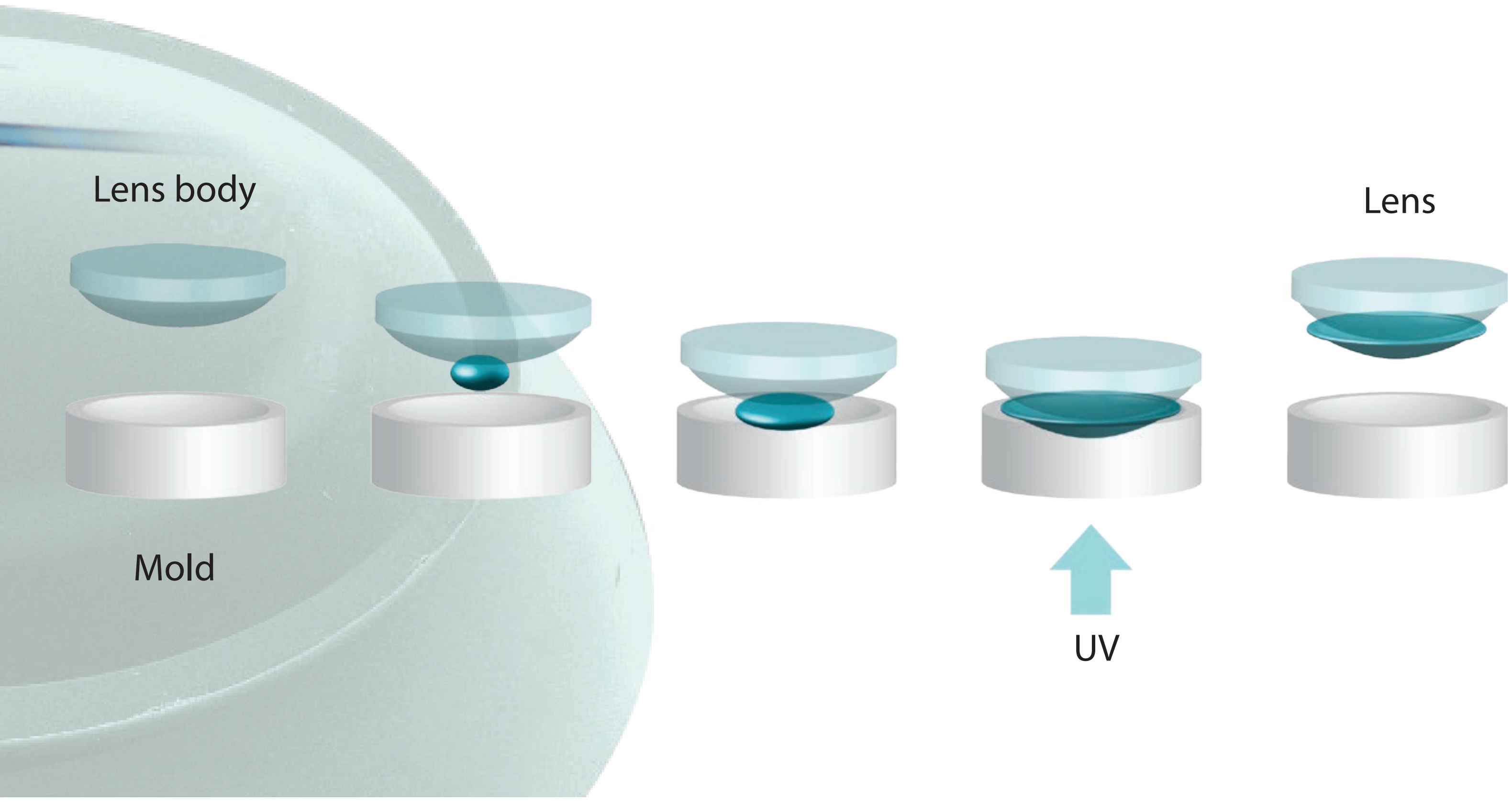

Materials for optical pickup lenses

Photo-rheology of a polymerization process

Photo polymerization has found many applications in the manufacturing of precisely structured components such as optical discs, gratings, lenses, and printed circuit boards. Among these, one of the most demanding applications is the manufacturing of aspherical lenses such as used for the read-out or writing of optical discs. Photo-rheology is an analytical tool used to optimize the polymerization process of the lens coating.

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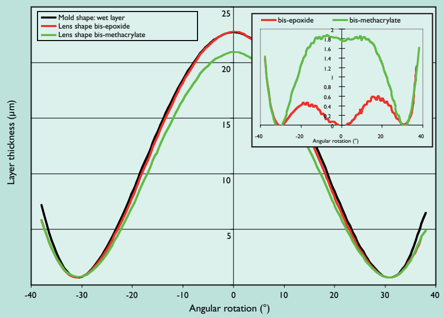

Fig. 1: Replica layer thickness of bis-methacrylate and bis-epoxide as a function of the position on the lens surface. The profile of the mold is also plotted. Thickness is obtained by subtraction of the body radius from the measured radius. Inset: indication of absolute deviation from the mold shape.

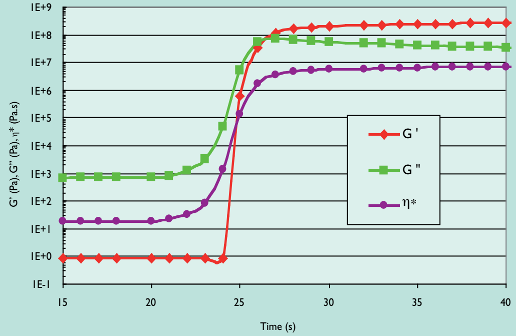

Fig. 2: Photorheological response of a bis-epoxide; exposure started at t = 20 s. The modulus of elasticity or storage modulus (G'), the loss modulus (G'') and the complex viscosity (η*) are plotted versus exposure time.

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Optical pickup lenses

Lenses obtained by the photo-replication process are made by applying a thin aspherically shaped plastic coating on a spherical lens body. This coating is obtained by filling the gap between the lens body and an aspherical mold with liquid monomer to which a small amount of a photo initiator has been added. The mixture is then turned into a glassy polymer by exposure to UV-light. Subsequently, the lens can be released from the mold. The frontpage shows both the lens replication process and the final resulting objective lens. The increase of storage capacity on optical discs implies the need of a better focused laser beam to read the data. As a result, more accurately shaped lenses are needed to focus the laser beam. These specially shaped lenses require coatings with a large aspect ratio.

Photo-rheology

Shrinkage during polymerization generally results in a change of the shape and / or the thickness of the coating cured in the mold. In practice the shape of the mold has to be corrected for this shrinkage. In addition to the overall shrinkage, the rheology of the polymerizing system is also of great importance: the earlier the system stiffens, the more difficult it will be to compensate for shrinkage. Rheology is a general term for "flow science". A rheometer is able to measure the resistance of fluids or (semi-)solids towards flow or deformation. Rheological properties such as viscosity, shear and loss modulus are determined in a rheometer. Photo-rheology allows one to monitor changes in rheological and mechanical properties during photo-initiated polymerization, when the material changes from liquid to solid.

Impact on lens replication

The shape of the lenses after replication depends (among other factors) on the choice of the starting materials. The performance of these materials in the lens replication process is determined by measuring the surface profile of these lenses. Subtracting the mold shape from the resulting surface profile provides direct information on the polymerization shrinkage (Fig. 1). The results from two different starting materials are shown.
From the figure it can be seen that the bis-methacrylate lens profile deviates most from the initial wet layer, while the bis-epoxide lens copies the shape of the mold with a much better accuracy. It appears that the bis-epoxide monomer exhibits almost no shrinkage at all. This unexpected behavior can be readily explained from the rheological response during cure (Fig. 2).

Rheology during polymerization

As Fig. 1 shows, the minimum layer thickness is about 0.7 µm. During polymerisation this minimum thickness (i.e. a narrow gap) limits the transport of monomer towards the centre of the lens. The transport can only take place as long as the sample is in the liquid state. This transportation period typically lasts 4 seconds: the modulus of elasticity (G') starts developing only after an exposure time of 4 seconds. After this period, the system develops elasticity. Finally, at the very end of the reaction, it vitrifies so it is no longer able to compensate for the shrinkage by a lateral flow, yielding a minimum stress. For the bis-methacrylate a totally different situation exists. Compared to the bis-epoxide, only a limited part of the reaction proceeds in the still liquid state. After stiffening, no monomer replenishment can take place through the narrow gap, so the system polymerizes more or less in a constrained volume. The accompanying stress causes a strong change of the shape upon release from the mold.
In conclusion, rheological analyses provide clear insight into the polymerization process and supply valuable information for the choice of applied materials.

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