Replication of MASS segmentators

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1 The need of replication

The Pupil Segmentation Unit, or *segmentators*, of MASS-DIMM instruments represent a system of small concentric mirrors with different tilts. The diameter of the outer mirror is 5.5 mm, the inner mirror has a diameter of 1.3 mm.

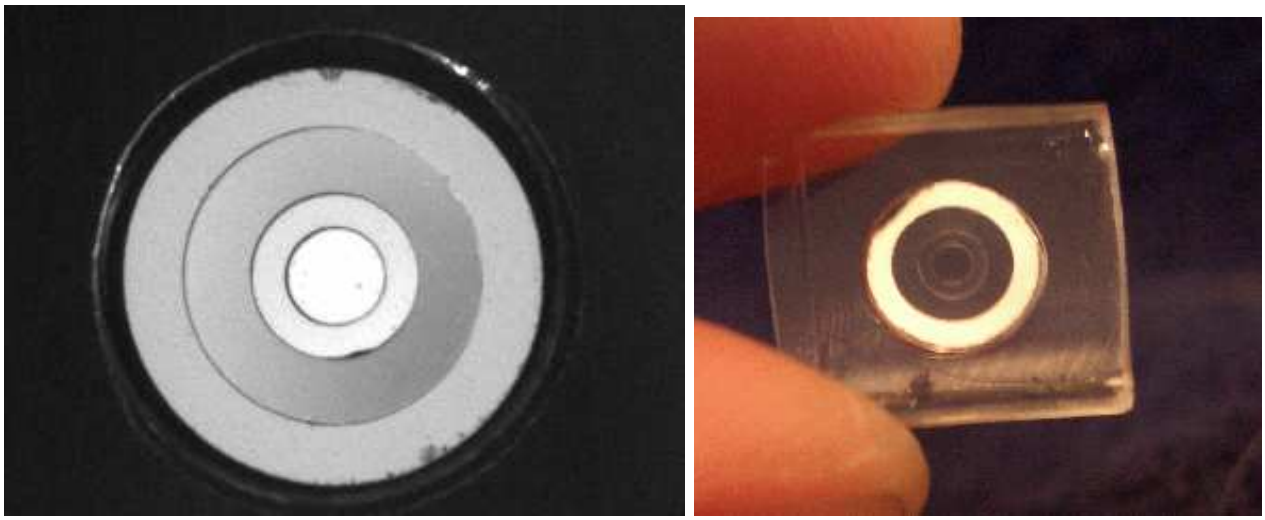

Figure 1: Left: photograph of the original segmentator in scattered reflected light. Right: a plastic replica of the segmentator.

Original segmentators are made from bronze. First, 4 tightly fitting concentric tubes of adequate diameters are machined and assembled. Then several such assemblies are ground and optically polished. The resulting common optical surface is concave (curvature radius 250 mm) and tilted by 8° with respect to the common axis of the cylinders. The surfaces are aluminized. When the segmentator is installed in the instruments, individual cylinders are turned by 30° with respect to each other, so that each segment directs its reflected beam to the corresponding re-imaging mirror.

The production of original segmentators is a custom process realized by S. Potanin (Moscow University). The quality of the resulting product is not uniform: some segmentators have scratches and polishing defects, as can be seen in Fig. 1. Moreover, the angles of each segmentator have to be aligned individually, which is a difficult and tedious procedure. Hence the idea of making plastic

replicas of some pre-aligned good-quality segmentator. That would ease the copying of MASS-DIMM devices, reduce production costs, simplify the alignment and assure uniform high quality. Additional advantage of replication is a possibility to shape the final segmentator for convenient mounting that would simplify or even obviate its alignment. However, this possibility is not used at present because the replicas are fitted into the existing mechanical design. The optical quality of the mirror segments does not need to be very high, only adequate collection of light is required.

2 Parameters and materials

It has been found in the initial experiments that good replicas can be produced by pressing some heated thermo-plastic polymer to the original segmentator, called master. The choice of possible materials is wide. However, the resulting surface will form a convex, not concave mirror, if used directly in reflection (Fig. 2). In this case, a special master with concave mirrors has to be made. An alternative solution would be to use the replica in transmission. The transmissive segmentator has additional optical surface, but its advantage is that the reflective layer is safely protected from outside. The optical parameters of the transmissive segmentator (inclination of segments to axis and optical power) are modified (increased) by the refractive index of the plastic material. Thus, in this case a fabrication of the special master is required as well.

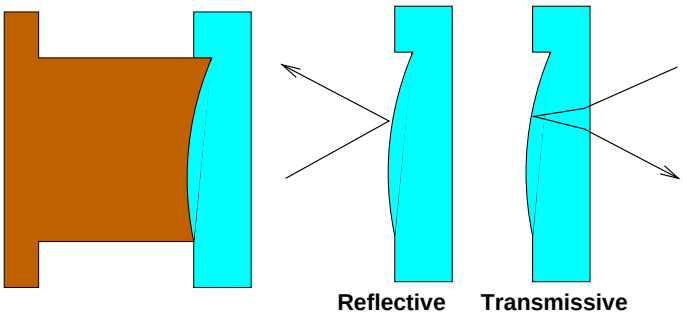

Figure 2: Scheme of reflective and transmissive replicas. For simplicity, only one mirror is drawn.

We selected the transmissive option. The plastic material chosen for replication is acrylic (polymethylmetacrylate, Plexiglas). It is readily available. The refractive index is $n_d = 1.492$, the dispersion is low (Abbe number $\nu_d = 57.8$). It has excellent transmission at visible wavelengths and absorbs UV radiation short-ward of 375 nm.

To account for the refractive index of acrylic, we decreased the inclination of mirrors to the axis from 8° to 5.3° and increased the curvature radius from 250 mm to 375 mm. The master was produced from the original segmentator. It was fixed in a large piece of bronze and re-shaped at the CNC milling machine for adequate curvature and tilt. The machined surface was polished.

The curvature of the original segmentator was selected in order to produce parallel beams after reflection. It turned out after initial tests that the replicas made from the newly machined master gave a too wide reflected beam that overfilled the re-imaging mirrors of MASS. This beam widening was caused by the poor optical quality of the master (especially its outer segment) which, unlike original, was produced by milling, not by optical polishing. Yet, the light concentration in the spots produced by the master was more than adequate. To correct the situation, I added some curvature to the front surface of the transmissive segmentator by replicating with a concave optical surface instead of flat.

A 10-mm lens with a concave surface of curvature radius 100 mm was used. This additional optical power made the light reflected by the segmentator to focus in small spots at the re-imaging mirrors. The size of these spots is small enough despite optical imperfections of the master.

3 Replication

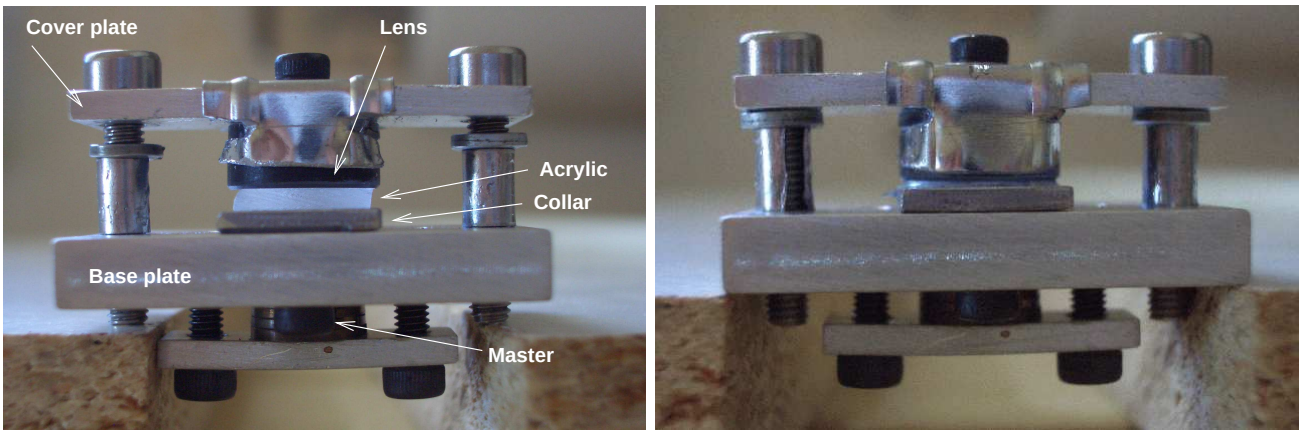

Figure 3: Before (left) and after(right) thermal molding.

The replication is illustrated in Fig. 3. First, the master is fixed in a special base plate and the clocking angles of its segment are aligned with a laser beam to be at 30° relative to each other. A round "collar" of 1.6mm thickness surrounding the master is installed to facilitate subsequent mounting of the finished segmentators. In the future, some other arrangement to shape the replicas can be made.

The upper (transmissive) surface is formed by pressing a concave lens. The lens is fixed (centered) to the cover plate that can be pressed by tightening 2 screws.

A small clean piece of 1.6-mm thick acrylic is placed between mandrel and lens and a slight pressure is applied. Then the whole assembly is heated over gas flame for 60-90 seconds, until the acrylic is softened. The softening is checked either by touching the extending parts of acrylic with an instrument or by the diminished force required to tighten the screws. The screws are tightened until the plastic is pressed inside the mandrel and fills it, assuring complete contact with the master.

After final tightening of the screws, the assembly is left to cool down. Then the lens is removed. Acrylic does not adhere to metal and easily detaches (Fig. 4, left). The replicas are examined for possible defects and mounted for subsequent aluminization. For mounting, two 1-mm holes are drilled outside work zone and a thin copper wire fixes the replicas to some substrate. Other mounting techniques are possible. Several replicas are aluminized jointly in a standard vacuum chamber.

4 Mounting and evaluation

The need to fit plastic replicas into existing mechanical design of MASS-DIMM instrument turned out to be quite constraining. Hopefully, a simpler mounting will be used in the future. Presently, the segmentators were fitted to the end of a cylinder of 6.5 mm diameter (Fig. 5, left). Given the outer

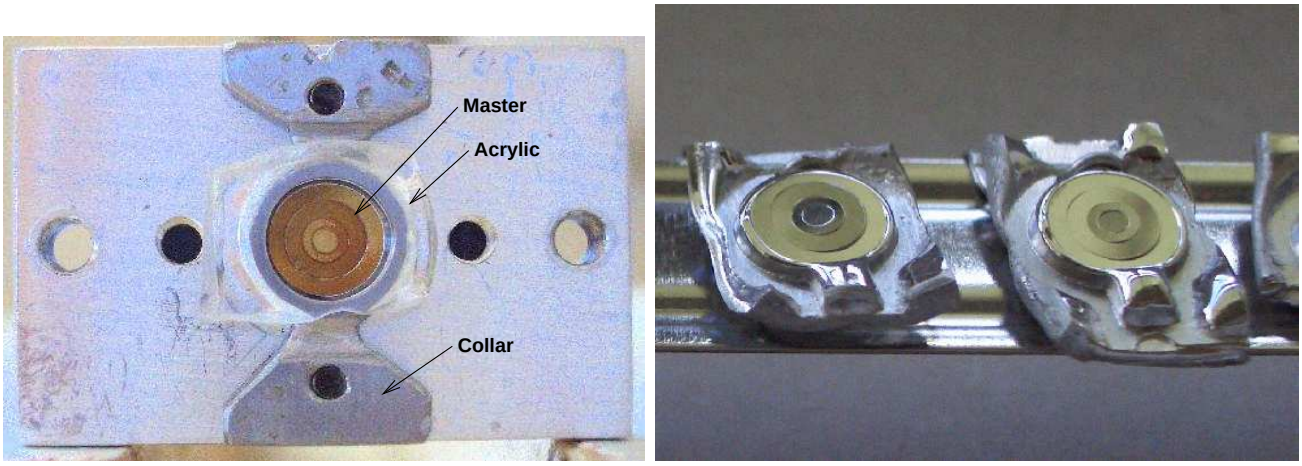

Figure 4: Replica immediately after cooling (left) and after aluminization (right).

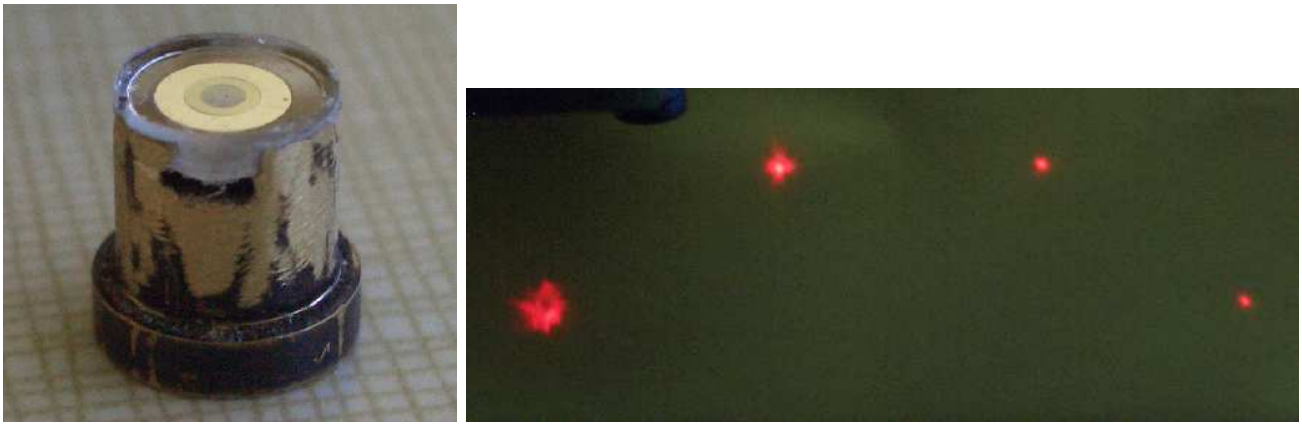

Figure 5: The mounted transmissive segmentator (left) and the spots formed by this segmentator (right).

segment diameter of 5.5 mm, this leaves very little space (0.5 mm) for support and edge treatment. The central work portion was cut down from the aluminized replicas and glued into the suitably machined cylinders. Any mechanical stress in the mounting had to be avoided, otherwise the plastic mirrors were distorted (astigmatism). Finally, the parts of acrylic protruding outside are removed and the finished product is installed in the MASS instrument. The only modifications of the mechanics required to take plastic replicas is the increased diameter of the segmentator holder.

The images of laser spots formed by the plastic segmentator in the actual MASS instrument are shown in Fig. 5, right. Some distortion of the largest spot (leftmost, segment D) is apparent. Yet, even this largest spot fits inside re-imaging mirror with a convenient margin around. In fact, this spot is smaller than the spot produced by the original segmentators.

5 Final remarks

The main difficulties encountered in the current production of plastic replicas are related to the small space available for their mount in the final MASS instrument. The replication itself goes very smoothly and reproducibly. There is no reason not to use this simple technique in the future. In the future designs of MASS-DIMM, full advantage can be taken of pre-aligned plastic segmentators that can be mounted very easily if a suitable shape is given to them in production. Cutting of the finished replicas should be avoided if possible. Masters of higher quality are desirable for future replication runs. Both transmissive and reflective segmentators are viable options.