CONF-9410382--1

UCRL-JC-118504
PREPRINT

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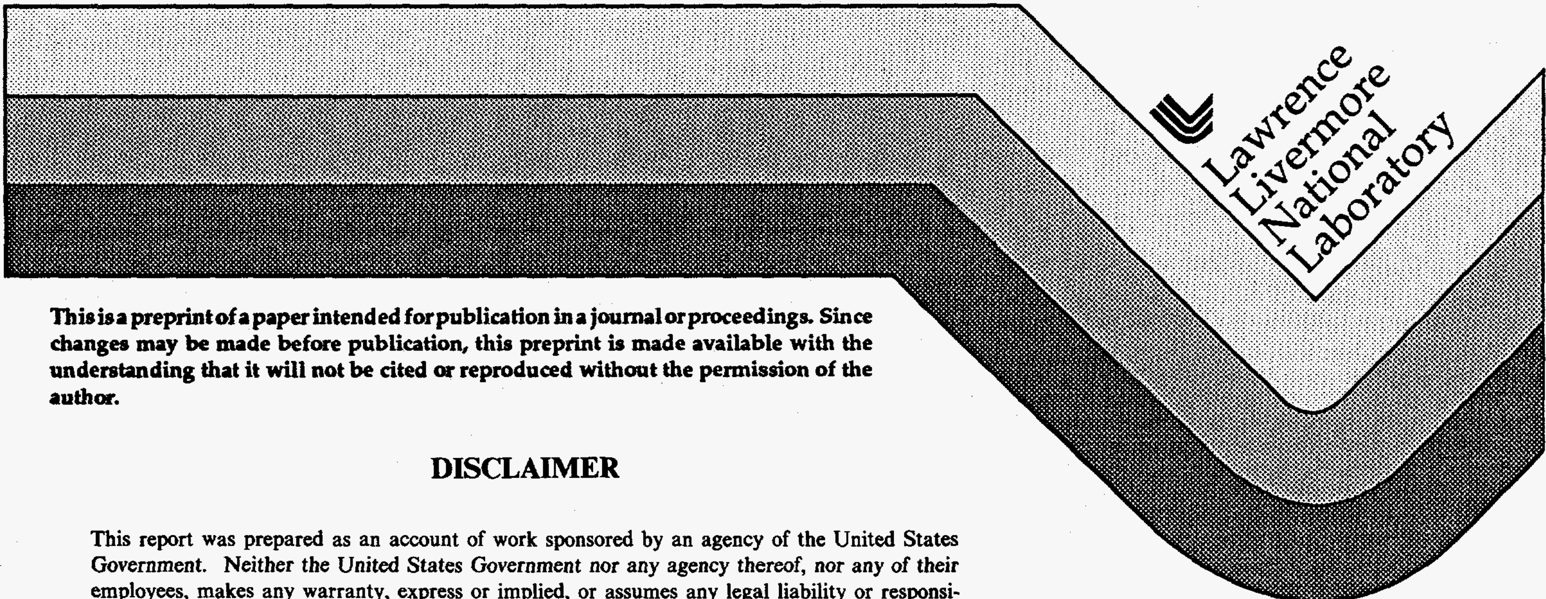
This paper was prepared for submittal to the
Annual Symposium of Optical Materials
for High Power Lasers
Boulder, CO
October 26–29, 1994

November 21, 1994



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Preparation of random phase plates for laser beam smoothing

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ABSTRACT

Phase plates are required for removing aberrations from laser beams caused by inhomogeneities in the optical components of the laser.

The first type of plate that we prepared consisted of a bi-level optical component that caused spatial smoothing of the beam by breaking it up into a fine scale spatial structure. This was made by etching a pattern directly into the substrate using HF/NH_4F. Components up to 80 cm in diameter were prepared but these are only 85% efficient because of beam losses in secondary maxima.

Multilevel designs are more efficient and we have prepared 5" diameter samples with 16 levels. These require four separate etch steps but have efficiencies greater than 90%.

2. INTRODUCTION

Directly driven targets for inertial confinement fusion (ICF) require laser beams with extremely smooth irradiance profiles to prevent hydrodynamic instabilities that destroy the spherical symmetry of the target during implosion.

Beams from large Nd:glass ICF lasers, such as the Nova laser at Lawrence Livermore National Laboratory (LLNL), typically have large scale inhomogeneities produced by the aberrations in the beam. These aberrations are caused by such sources as optical inhomogeneities, surface figure errors, thermal nonuniformities and diffractions from segmented optical components. One technique for improving the quality of laser beams is by spatial smoothing in which the beam is broken up into a fine scale spatial structure that the target can potentially smooth by thermal conduction. This approach was first used by Kato et al.[1] who used a bilevel random phase plate (RPP) for ICF target experiments. An example of this type is shown in Fig. 1. The pattern consists of a contiguous layout of regularly spaced elements, usually hexagonal, randomly selected to be either on or off. The on elements impose a Π phase shift on the beam relative to the off elements. The far field intensity pattern with hexagonal elements concentrates about 84% of the total energy in the central maximum. This is the energy that falls on the target and 16% is therefore lost. This loss is significant because of the corresponding increase in cost of the entire system for delivering a fixed amount of energy to the target. More efficient designs, called kinoform, have been developed by Dixit et al.[2] for ICF application. A typical design consists of 16 levels of square elements and this can concentrate about 95% of the energy in the central maximum. A comparison of the energy distribution of kinoforms and random phase plates is shown in Fig. 2.

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Our investigations in this field started several years ago with the initial preparation of large, 80-cm-diameter, random phase plates for use on the Nova laser.[3] These were prepared by coating a substrate with a sol-gel silica layer of the correct thickness and then etching a suitable pattern in the layer using photoresist and very dilute HF solution. The method was time-consuming but samples were produced that performed quite well on the laser. Recently we have found that a pattern can be directly etched into a silica substrate using a buffered HF-NH_4F etchant and photoresist. We were able to prepare both simple binary phase plates and the more complex kinoform plates by this method and this is described below.

3. BINARY PHASE PLATES

The process used for the preparation of these plates was similar to that used by us earlier for the sol-gel pates[3] and is illustrated in Fig. 3. The photoresist layer was spun coated on the substrate in the normal manner, exposed through a suitable mask and developed to give the RPP pattern. We found that it was essential that the substrate be scrupulously clean (dilute NaOH was followed by UV/O_3 exposure) and that a coupling agent (HMDS) be used otherwise the photoresist layer would sometimes lift off and fail to protect the underlying substrate during the subsequent etch.

Our etch both consisted of an aqueous solution of 1% HF plus 15% NH_4F which was continually stirred and kept at a constant temperature of 25°. The etch rate was approximately 20 nm/min. and was determined by the use of witness samples. The required etch depths for 527 nm and 355 nm light were 573 nm and 386 nm respectively and we were able to consistently come within ± 2% of these figures.

After etching, the remaining photoresist was removed from the sample and it was ready for use. RPP's were prepared by this method on 65-cm and 80-cm-diameter fused silica substrates, which also served as debris shields, for use on the Nova laser at LLNL and the Phebus ICF laser at the Limeil Laboratory in France.

The optical performance of all these samples was near theoretical and there were no other problems. In particular there was no problem with laser damage because the process, being an etch, in many cases removes absorptive contaminants from the silica surface. The threshold can therefore increase over that of bare polished silica which is normally very high in the first place.

4. KINOFORM PLATES

We prepared the more complex kinoform plates by a similar process to the binary plates except that four steps with four different masks were required. Our initial design required 16 levels of square pixel arrays with a maximum phase delay of 2π. For 527 nm light this required a total etched depth of 1146 nm (i.e., 71.6 nm/level).

Sixteen layers can be prepared with only four masks as illustrated in Figs. 4 and 5. The first pattern was prepared in photoresist using mask #1 as described in the previous section and the bare areas etched to a depth of exactly half of the maximum required. These are the areas marked 1 in Fig. 4. The resist was then removed, the sample recoated and exposed to mask #2. This mask must be aligned accurately with the pattern already etched to exactly half the depth of the previous etch. These sections are marked 2 in Fig. 4.

The process was repeated twice more to give the etched areas marked **3** and **4**. Typical etching times and depths are shown in Table 1 and the final result was the multilevel sample shown in Fig. 4.

We prepared several 5" diameter kinoform designs with 300 micron square elements on 6" diameter fused silica substrates. These were evaluated on a test bench with 514 nm light and found to contain greater than 90% of the incident light inside the desired 500 micron focal spot. While this is considerably better than an equivalent RPP, its efficiency is still less than the theoretical which is about 95%. Dimensional instability in the photographic film masks and errors in the printing of the patterns were thought to have contributed to the loss. There were misalignment errors up to 15 microns in some areas which would cause light loss from diffraction.

Our dimensional stabilities should be solved by the use of chrome on silica masks and these will be printed and used in a constant temperature room. Ultimately we will have to produce samples up to 40 cm x 40 cm with precision in the 1-2 micron range.

As with RPP's, the laser damage thresholds of these 6" parts were not a problem and several samples had thresholds higher than the original unetched substrates.

5. SUMMARY

We have prepared binary random phase plates on fused silica substrates up to 65 cm diameter by a photolithographic and HF/NH_4F process. These have been used on the Nova laser and found to perform close to their theoretical efficiency of about 84%.

By a similar process we have also prepared 16 level kinoforms on 6" diameter fused silica substrates. These have performed at about 90% efficiency rather than the theoretical of about 95%. Performance loss is thought to be due to dimensional instability of the four pattern marks leading to misalignment of the kinoform pattern.

The laser damage thresholds of both RPP's and kinoforms has been as good as or better than the bare silica substrates.

6. ACKNOWLEDGMENTS

Work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. W-7405-ENG-48.

7. REFERENCES

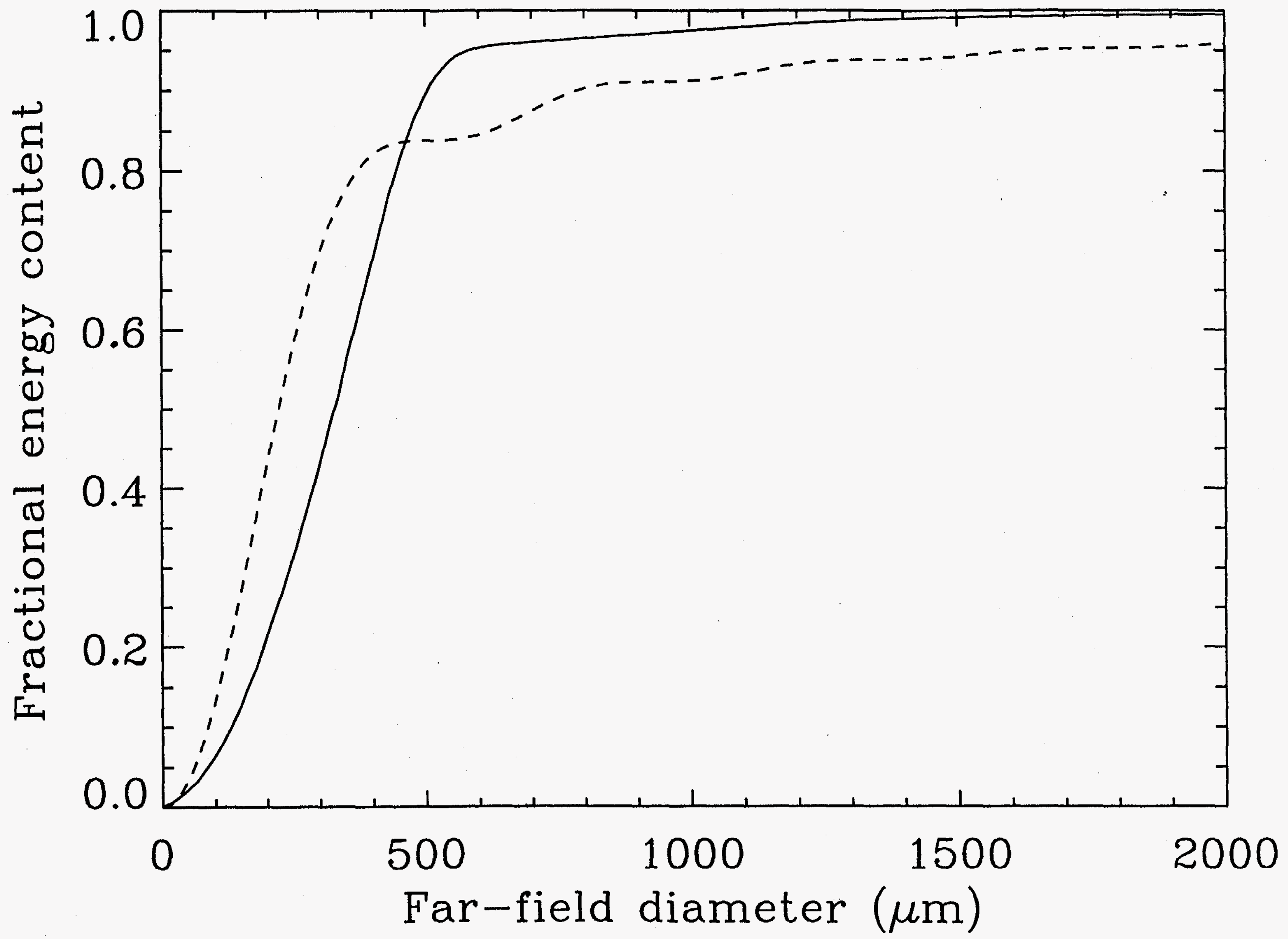
[1] Y. Kato, K. Mima, N. Miyanaga, S. Arinaga, Y. Kitagawa, M. Nakatsuka and C. Yamanaka, "Random phasing of high power lasers for uniform target acceleration and plasma instability suppression," Phys. Rev. Lett. **53**, 1057-1060 (1984).

[2] S. N. Dixit, J. K. Lawson, K. R. Manes, H. T. Powell, and K. A. Nugent, "Kinoform phase plates for focal plane irradiance profile control," Optics Lett. **19**, 417-419 (1994).

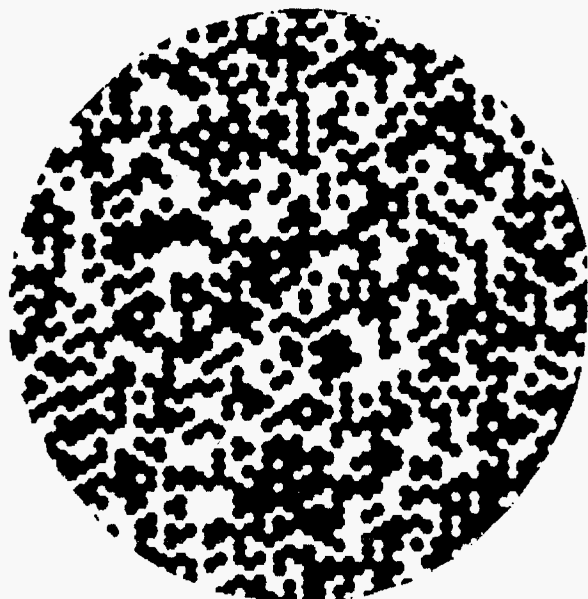
[3] S. N. Dixit, I. M. Thomas, B. W. Woods, A. J. Morgan, M. A. Henesian, P. J. Wegner, and H. T. Powell, "Random phase plates for beam smoothing on the Nova laser," Appl. Opt. **32**, 2543-2554 (1993).

We use a photoresist and etch process to produce the RPP pattern

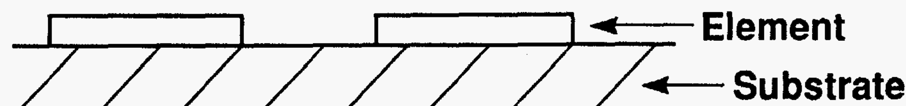
70-37-1094-3578
18IMT/lwh


Fractional energy content
1.0
0.8
0.6
0.4
0.2
0.0
0
500
1000
1500
2000
Far–field diameter (μm)

Binary RPP's have two surface levels



Random distribution of
hexagonal elements (~5 mm)
up to 80 cm diameter



Relative optical phase delay of π
between the off and on elements

70-37-1094-3579
18IMT/lwh

Only four masks are required to give sixteen levels

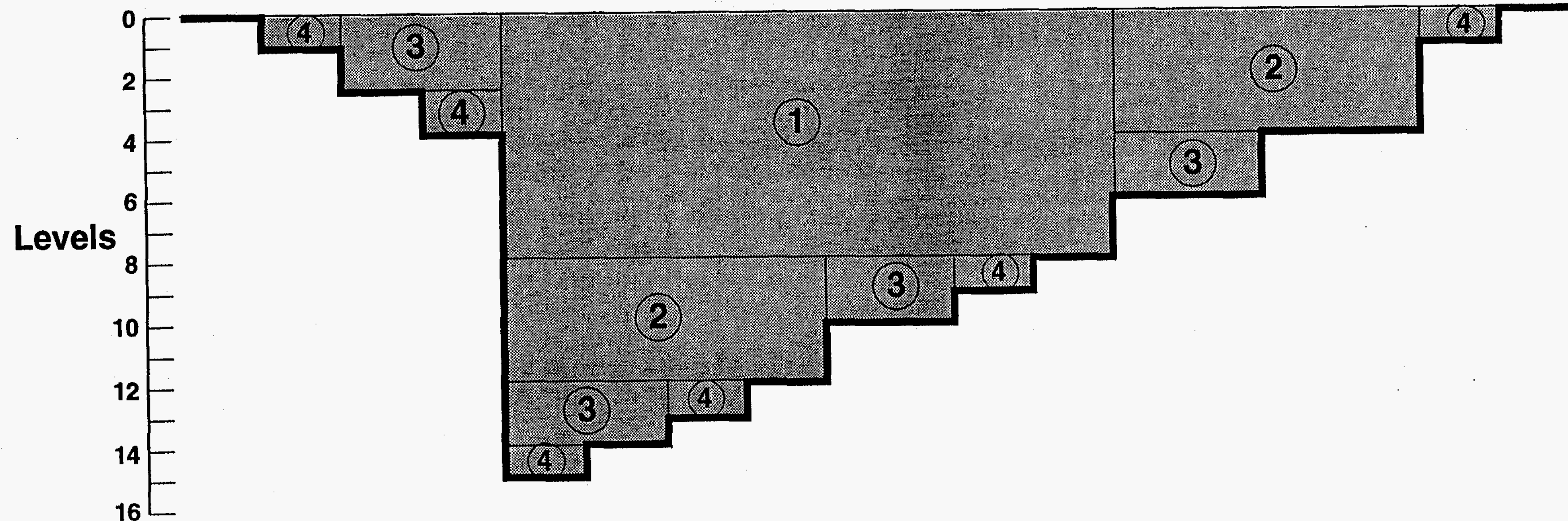
Masks

4

3

2

1



70-10-0994-3498
27IMT/gbh

Conditions for kinoform etch