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Fabrication of Large Aperture Kinoform Phase Plates in Fused Silica for Smoothing Focal Plane Intensity Profiles

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ABSTRACT

We have fabricated large aperture (40-cm) kinoform phase plates for producing super-Gaussian focal plane intensity profiles. The continuous phase screen, designed using a new iterative procedure, was fabricated in fused silica as a 16-level, one-wave deep rewrapped phase profile using a lithographic process and wet etching in buffered hydrofluoric acid. The observed far-field contains 94% of the incident energy inside the desired spot.

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In laser driven inertial confinement fusion systems, it is necessary to produce smooth focal plane intensity profiles [1]. The desired intensity distribution consists of a superGaussian envelope with a superimposed speckle on it. The speckle pattern is smoothed either by the plasma or by other temporal smoothing techniques. Binary random phase plates (RPPs) are inadequate for spatial smoothing as they lead to Airy function envelopes in the far-field and are only 84 % efficient. Furthermore RPPs also introduce large intensity modulations in the propagated intensity past the RPP which can potentially damage the optics downstream from the RPPs.

In order to overcome these limitations of the RPPs, we have recently designed new phase plates for producing superGaussian focal plane intensity profiles. Such phase plates consist of smoothly varying phase profiles only a few waves deep. The propagated field past such a KPP exhibits a low level of intensity modulation. The absence of 2π jumps also eliminates the large angle scattering losses from these edges and increases the energy concentration inside the central spot. The calculated far-field profile contains greater than 98% of the incident energy inside the superGaussian spot.

The kinoform phase plates can be fabricated either as a several waves deep smooth surface relief pattern or as a one-wave deep pattern after re-wrapping the phase. The latter design contains 2π jumps that occur either as closed loop structures or as lines extending from one edge to another edge on the input aperture. Use of the phase plates in fusion laser systems also requires that they be resistant to optical damage under high fluence irradiances (several J/cm2). Moreover, the phase plates have to be located at the end of the fusion laser chains (where the laser beam size is large ~ 40 cm for the Beamlet laser) in order to prevent any potential optical damage to downstream optics. These requirements imply that the phase plates have to fabricated on large fused silica substrates.

Fabrication of continuous phase plates requires patterning the required surface relief structure in a photoresist layer and its subsequent transferring into fused silica by some form of dry etching (reactive ion etching or chemically assisted ion beam etching). The aperture sizes that can be fabricated using this approach are currently limited to a few centimeters in diameter due the size of available ion etching machines. On the other hand, a one wave deep, mod-2π phase profile can be easily fabricated using the lithographic process with binary masks and wet etching of fused silica in hydrofluoric acid. We have demonstrated the scalability of such process to large apertures (up to 80-cm diameter) in our binary RPP fabrication for smoothing the Nova laser focal spot. For these reasons we have chosen to fabricate 40-cm size KPPs in fused silica using the multiple-mask, wet-etch method.

The continuous KPP phase screen was first rewrapped to a one-wave deep structure and was quantized to 16 levels. This quantized phase screen can be fabricated using four binary masks combined with differential etching for each mask step. This quantization leads to about 1% decrease in the efficiency.

The required binary masks were patterned in chrome coated fused silica substrates by patterning an overlayer of photoresist and etching away the unprotected chrome. We used fused silica substrates for the masks as well in order to equalize the thermal expansion coefficients of the KPP and the mask substrates. The mask substrates (also ~40 cm)were chrome coated by vapor deposition and were subsequently coated with a ~ 350 nm layer of photoresist using a large aperture meniscus coater developed at our Laboratory. The patterning of the photoresist was done on a large aperture photoplotter developed in our laboratory. Here the photoresist is exposed by delivering the 414 nm light from an Kr-ion laser through a 300 μm aperture placed approximately 15 μm above the substrate. The long time required for writing the masks (~3 days for each mask) required us to control the temperature of the plotter table (made of aluminum) to 0.02 degrees centigrade throughout the plotting period. This enabled us to prepare the binary masks with about 1μm precision (positioning as well as pixel size) over the entire aperture.

The KPP was fabricated by transferring these binary patterns into a photoresist layer deposited over the fused silica substrate by exposing under a UV lamp, developing away the exposed resist and etching the unprotected fused silica in a buffered hydrofluoric acid solution. This process was repeated for each of the four masks. The etch depth for the first mask step is $\lambda/2(n-1)$ where λ is the operating wavelength (351nm) and n the substrate refractive index at this wavelength. It is reduced by a factor of 2 with each subsequent mask step. The alignment accuracy between various masks is about 1-2μm.

To evaluate the optical performance of the 16-level KPP, we illuminated a 30-cm diameter portion of the KPP by a spatially coherent 351 nm laser and investigated the focal plane irradiance distribution produced by it. Preliminary results indicate that the far-field spot resembles a super-Gaussian and contains approximately 94% of the incident energy inside it. This compares well with the predicted efficiency of about 97% after allowing for the quantization and mask misalignment losses. Detailed results including the sources of the efficiency loss will be discussed during the presentation.

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References:

[1] J. D. Lindl et al *Physics Today* **45** 32 (1992)

[2] S. N. Dixit et al (preceding paper).

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Introduction

- High power fusion laser systems require spatial and temporal beam smoothing for efficient laser energy coupling to the target
- We require top-hat focal plane irradiance profiles with high (>95%) energy concentration within the spot
- Efficient redistribution of the laser enrgy in the focal spot can be achieved using kinoform phase plates (KPP)
- To avoid laser damage to down stream optics the KPPs have to placed as the last optical component in the beam
- This requires us to make KPPs on large aperture (~50 cm) fused silica substrates

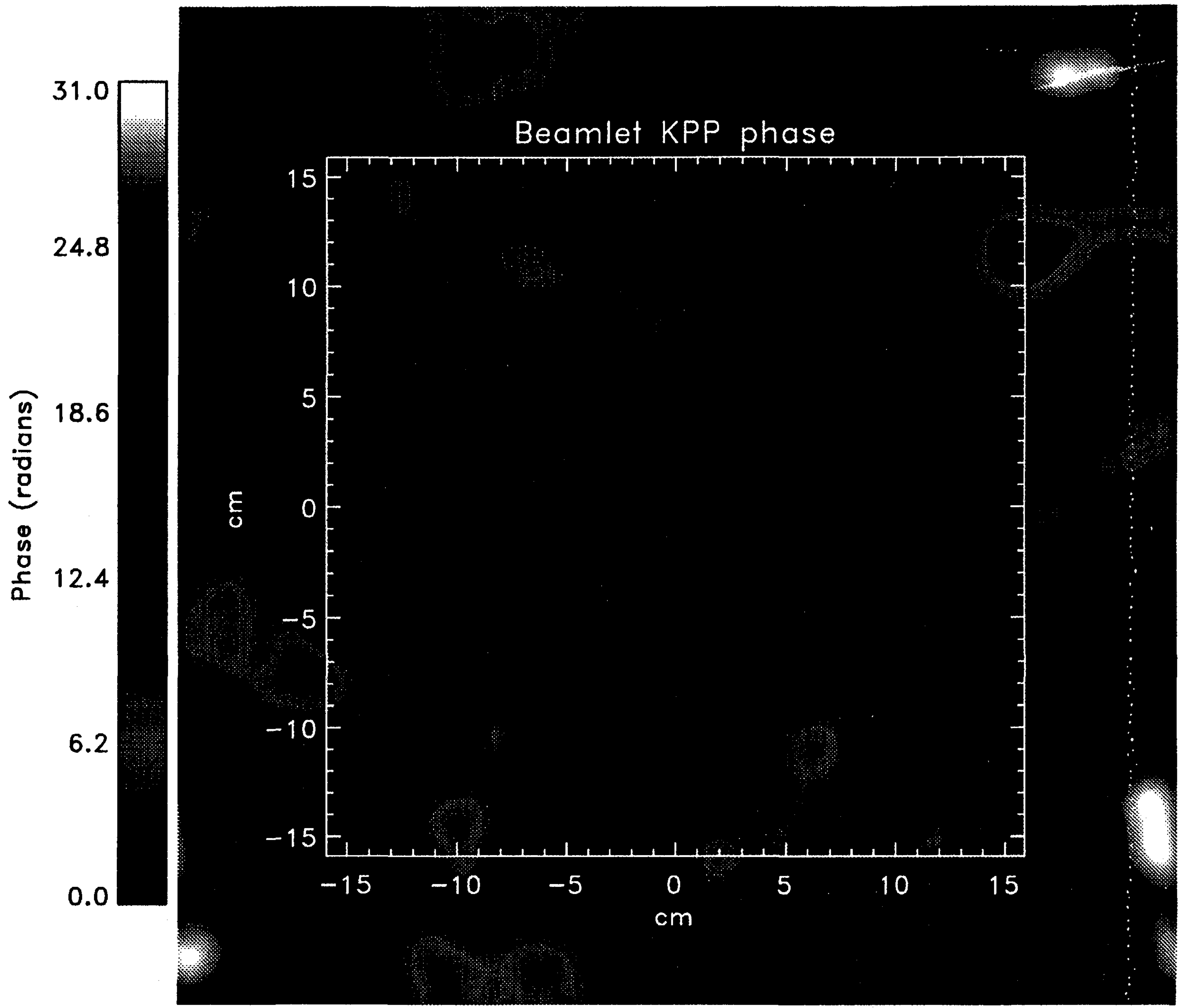
Design parameters for the Beamlet KPP

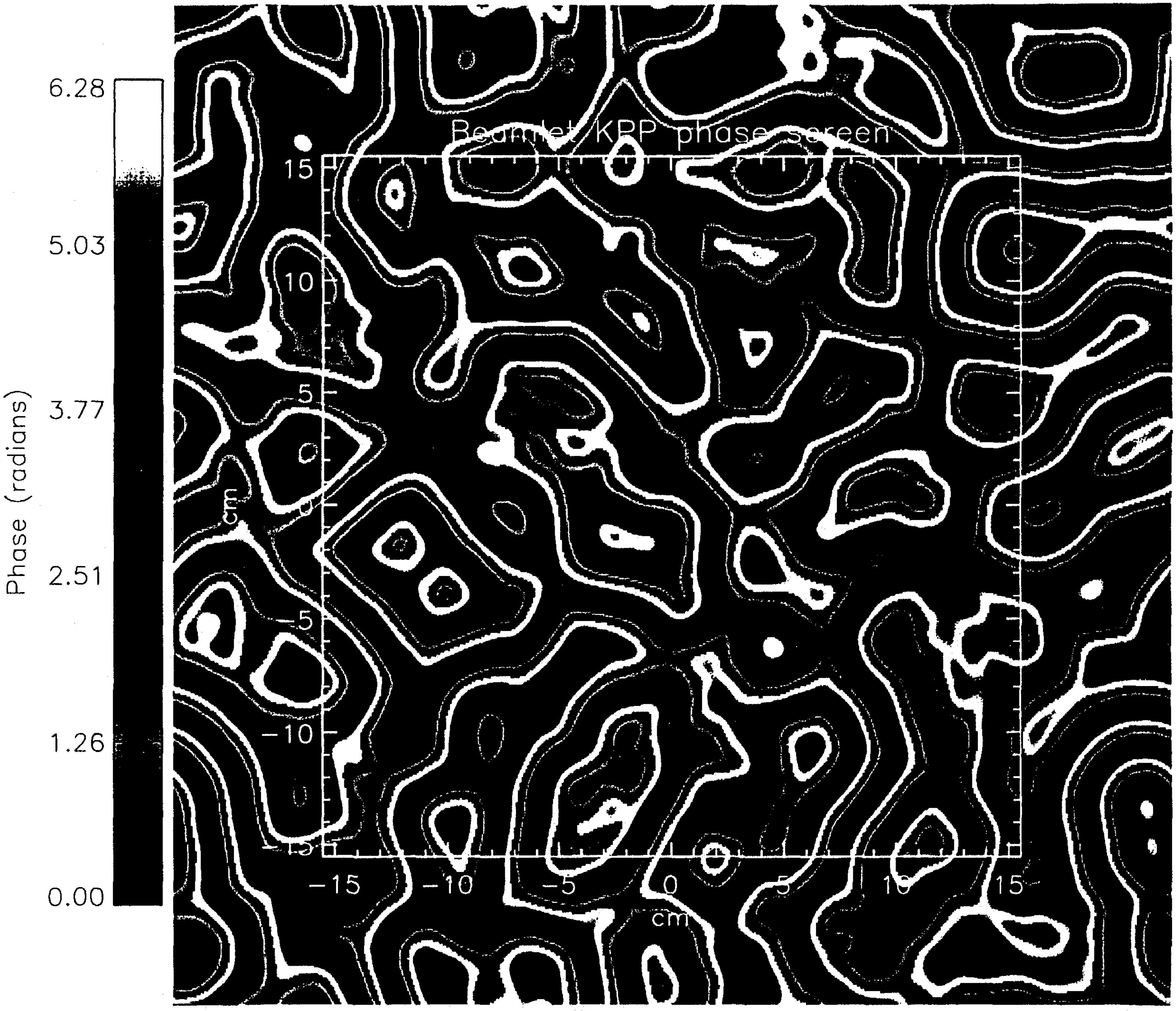
- Fully contiuous phase screen was designed to give a 350 μm diameter superGaussian spot for an unaberrated beam (smaller than the required 500 μm diameter chosen to allow room for aberration induced broadening of the spot)

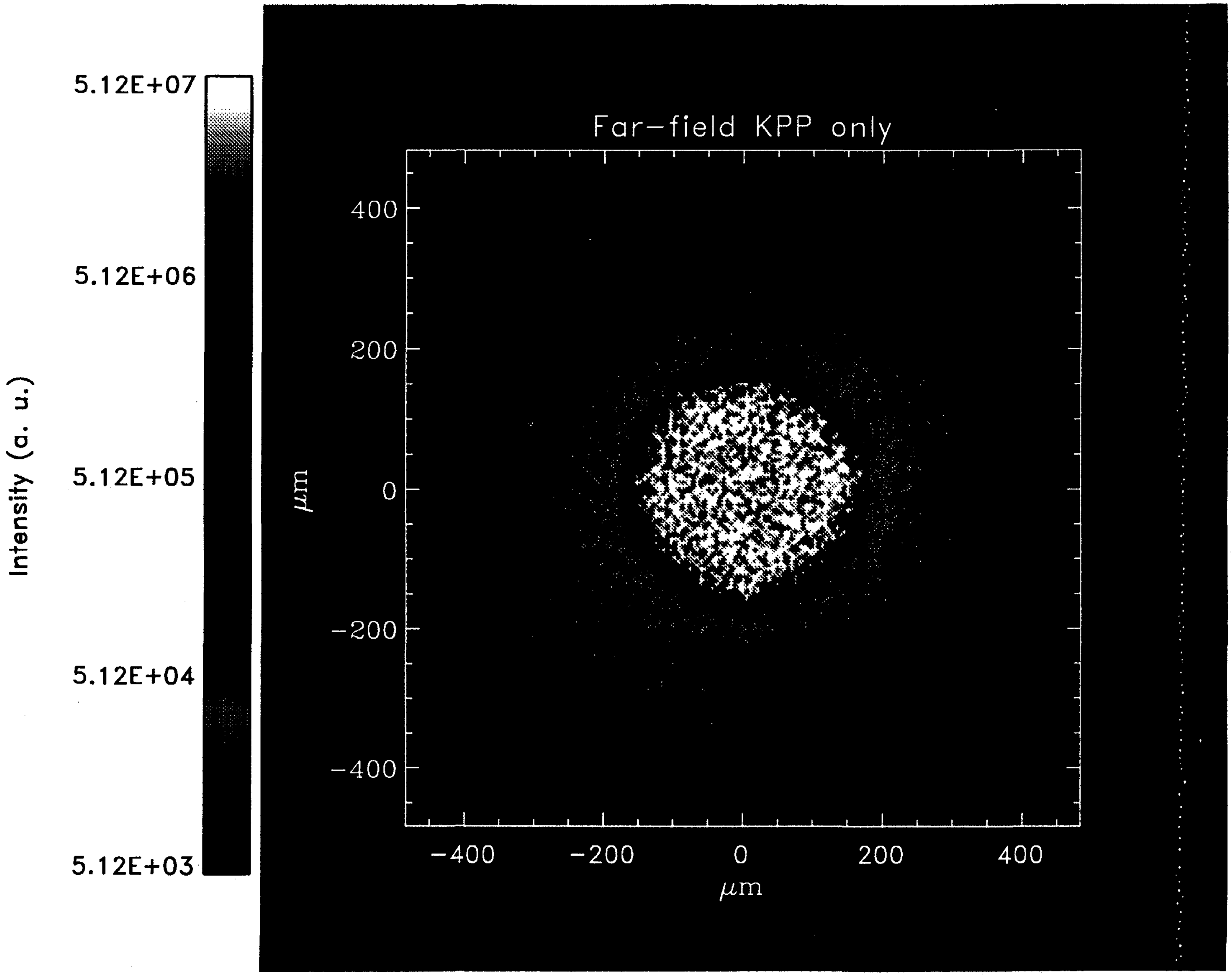
- Phase screen re-wrapped to mod 2π, quantized to 16 levels and fabricated in full-aperture, fused silica beamlet debris shield using a four-mask, wet-etch process

- Quantization loss: 1%
  Pixelation loss: 0.2%
  Mask misalignment loss 1.5%
  (5μm error per mask - conservative)

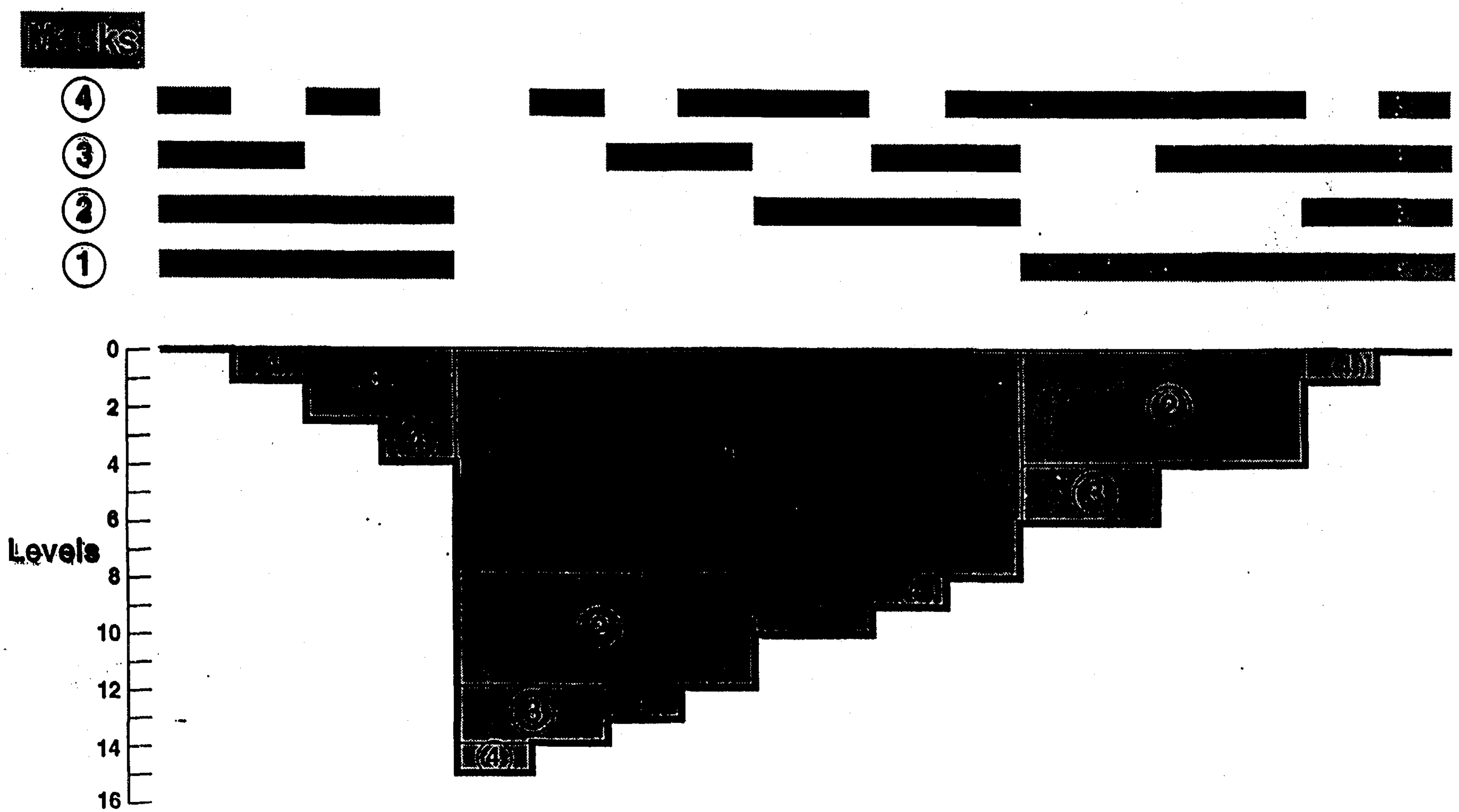
Total loss ~3% ⇒ KPP efficiency 97%


Beamlet KPP phase
Phase (radians)
31.0
24.8
18.6
12.4
6.2
0.0
15
10
5
0
−5
−10
−15
cm
−15
−10
−5
0
5
10
15
cm


Beamlet KPP phase screen
Phase (radians)
6.28
5.03
3.77
2.51
1.26
0.00
cm
cm
15
10
5
0
−5
−10
−15
−15
−10
−5
0
5
10
15


Far−field KPP only
5.12E+07
5.12E+06
5.12E+05
5.12E+04
5.12E+03
Intensity (a. u.)
400
200
0
−200
−400
μm
−400
−200
0
200
400
μm

A sixteen-level profile can be fabricated in fused silica by four binary masks and differential etching in HF



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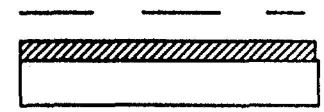
Lithographic method of KPP fabrication

Coat the fused silica substrate with photoresist

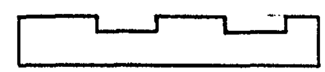
Expose through a binary mask



Develop resist

Etch the pattern into fused silica substrate

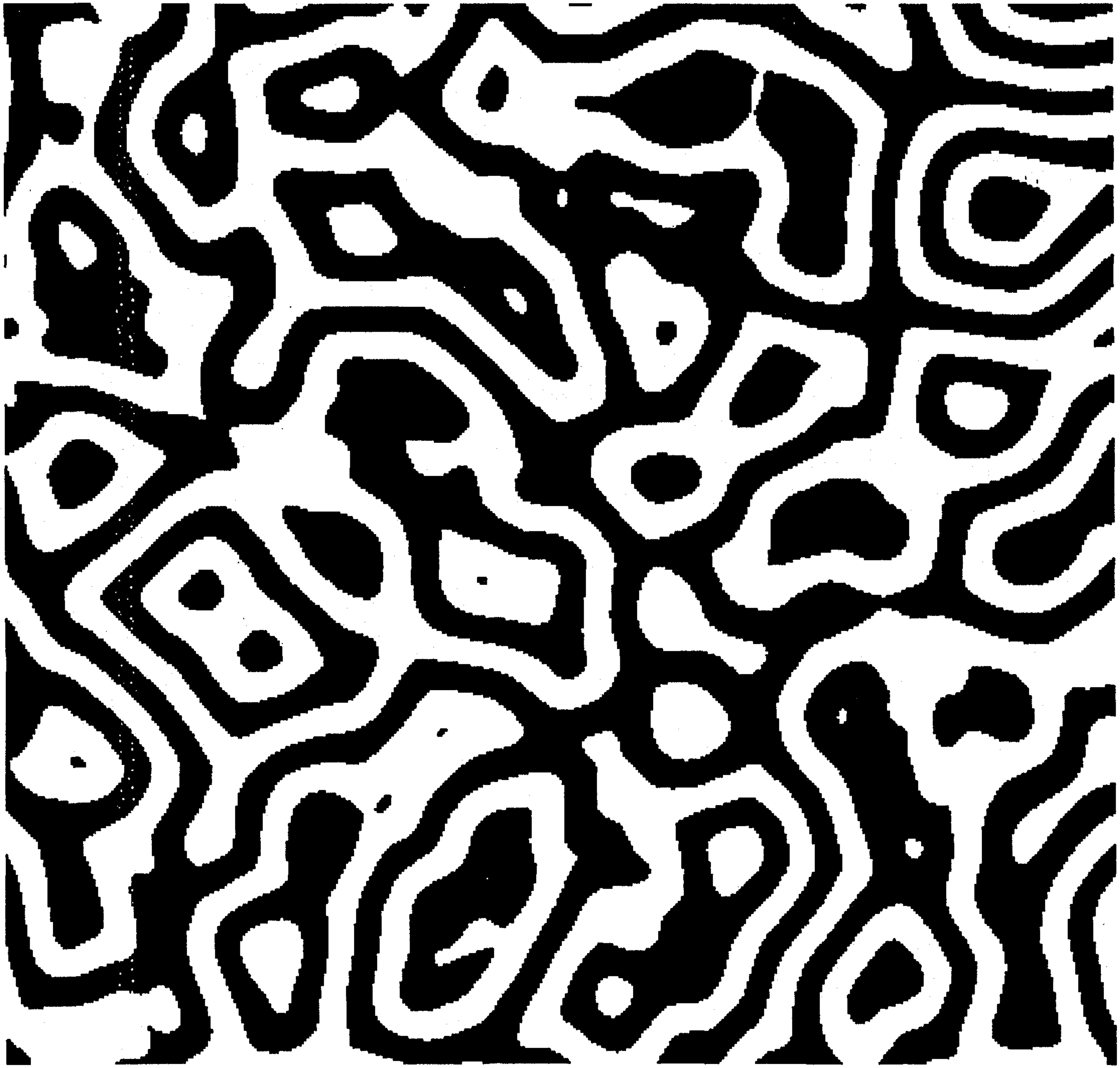
Wash off the resist



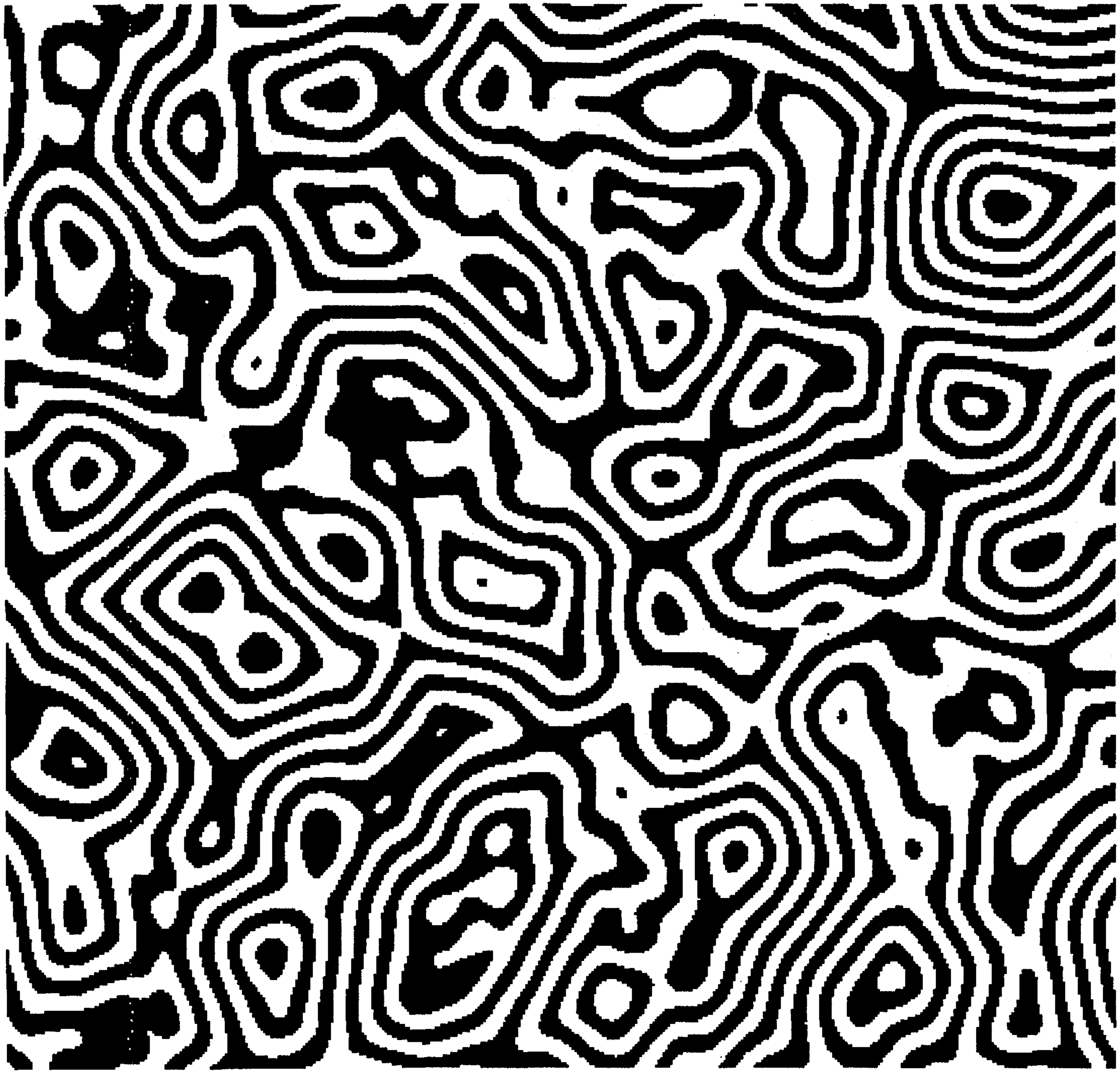
Binary masks are prepared by patterning a photoresist layer using the Gerber photoplotter in B298

Above sequence of steps is repeated for each mask

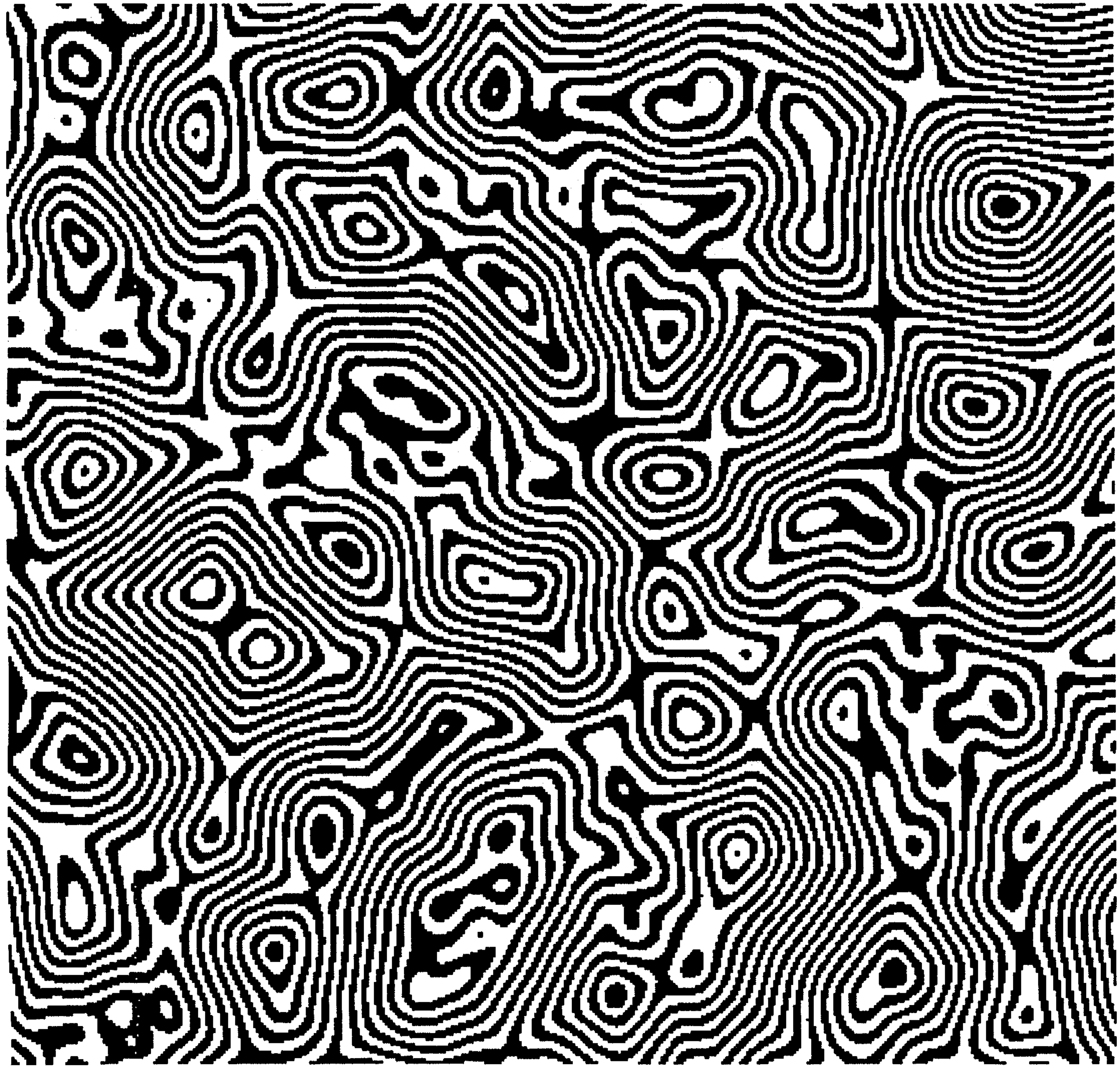
Mask 1



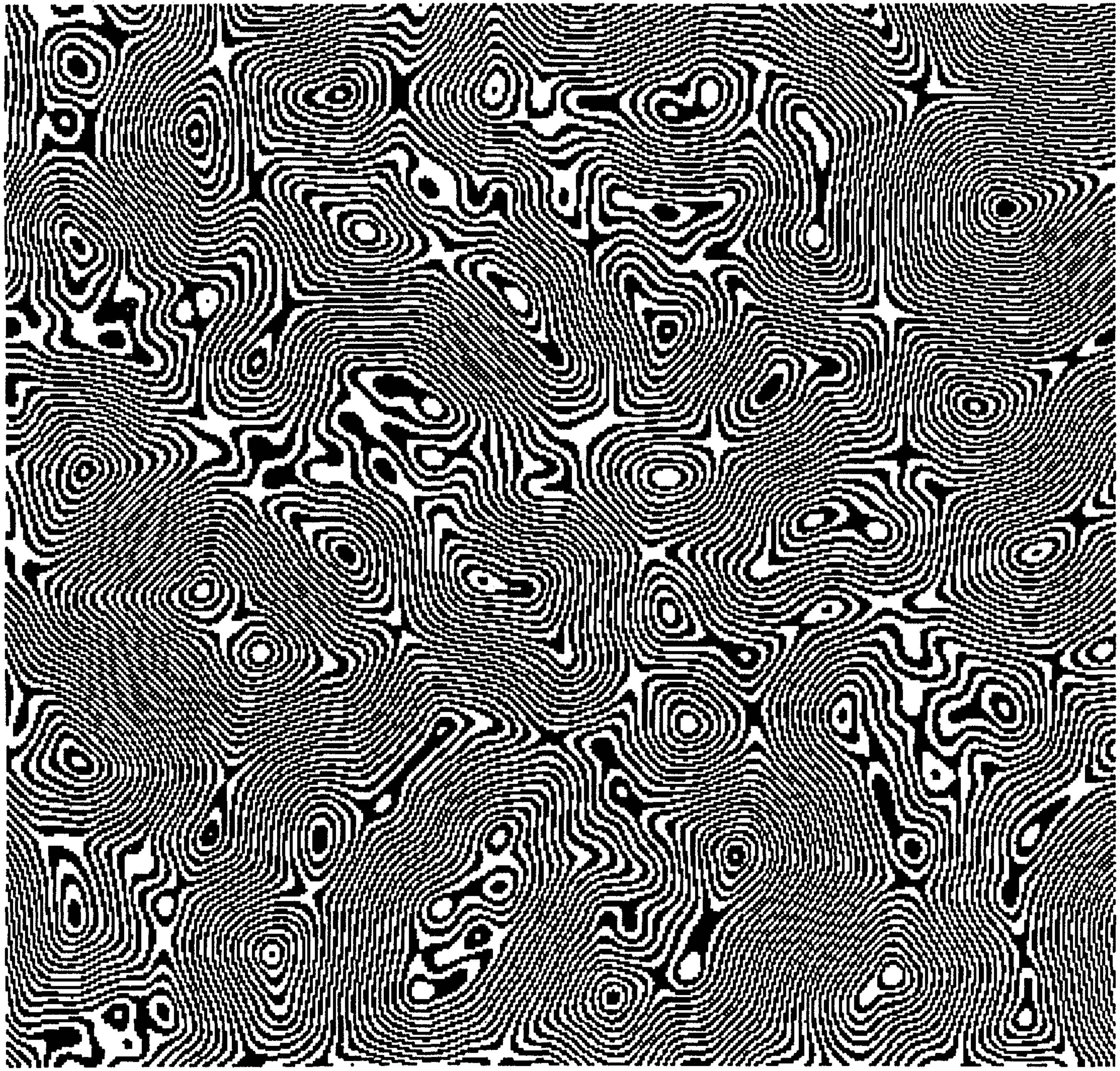
Mask 2



Mask 3



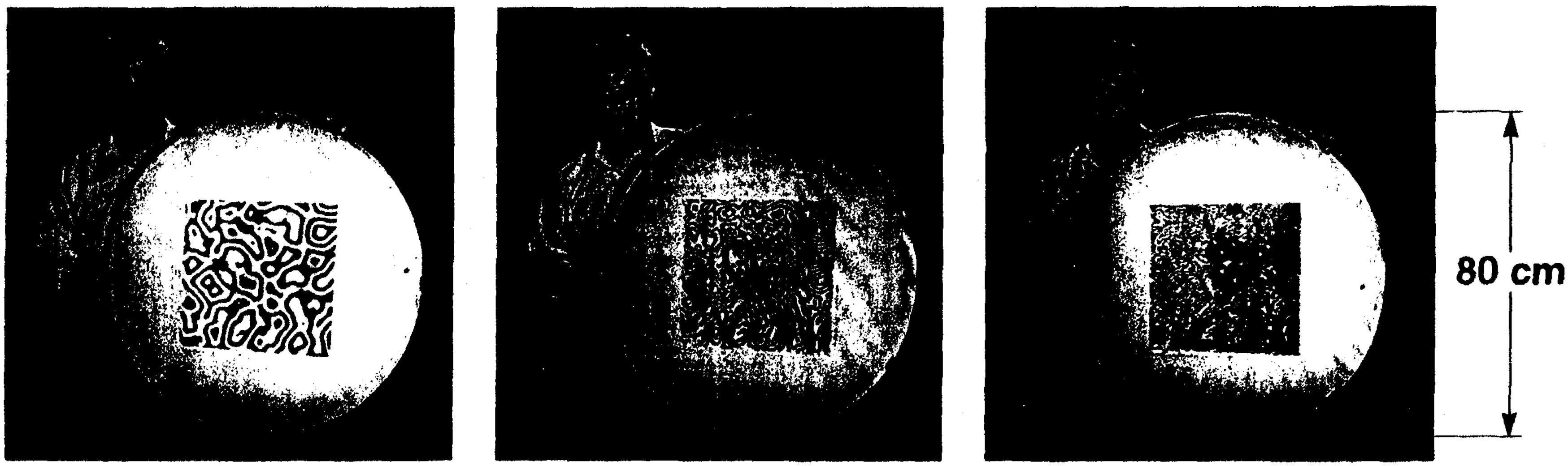
Mask 4



The full scale (80 cm) photoplotter for phase-[illegible] mask [illegible] is operational

Binary masks are patterned in chrome coatings on fused silica substrates using the large-aperture photoplotter

- Fused silica substrates are used for masks since their material properties are the same as those for the KPP substrate



- Chrome coating by vapor deposition
- Photoresist coat over chrome using large-aperture meniscus coater
- Pattern resist using the photoplotter
- Develop resist
- Etch unprotected areas of chrome

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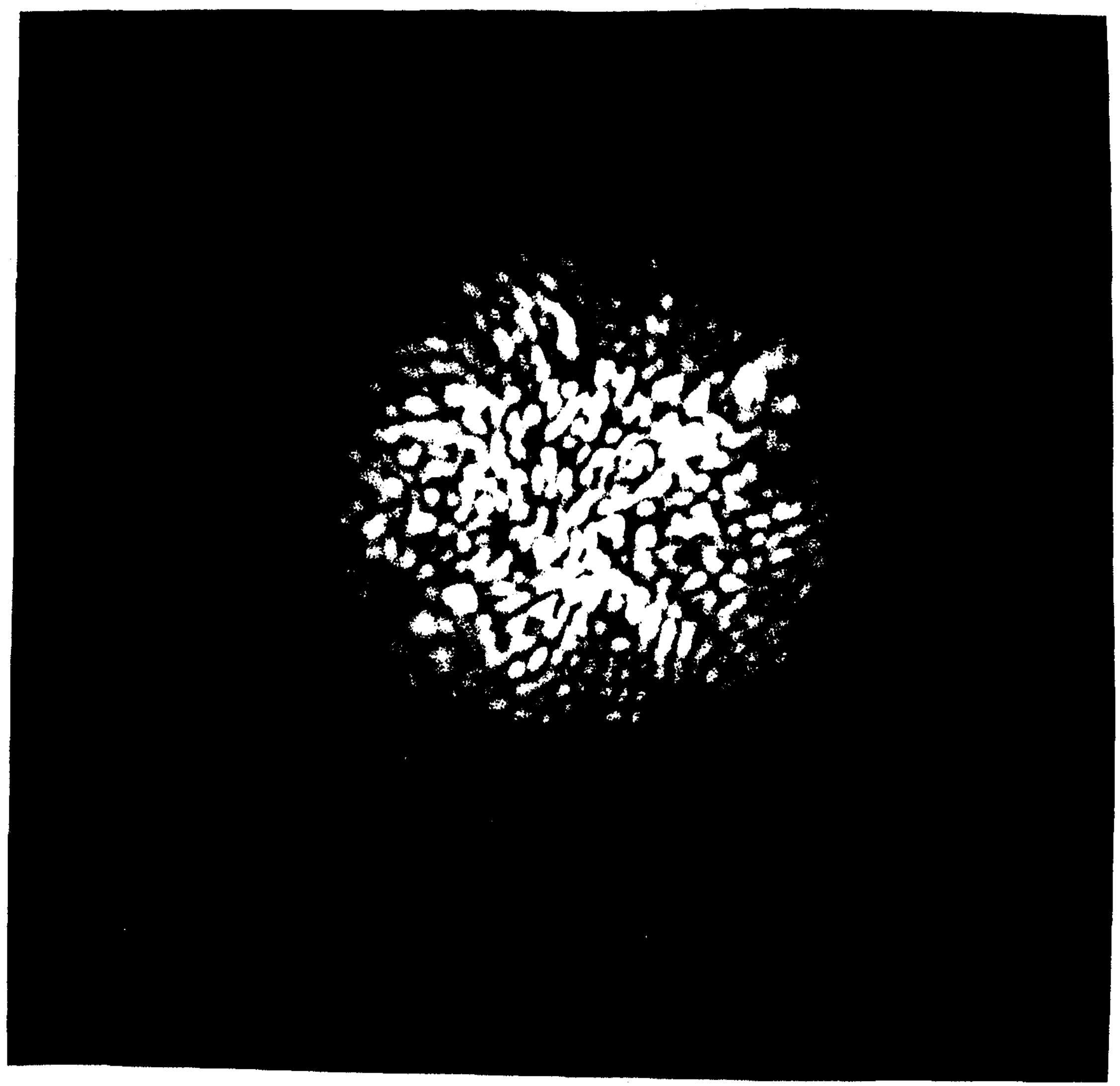
Far-field image of BKPP2 in the off-line phase-plate diagnostic station



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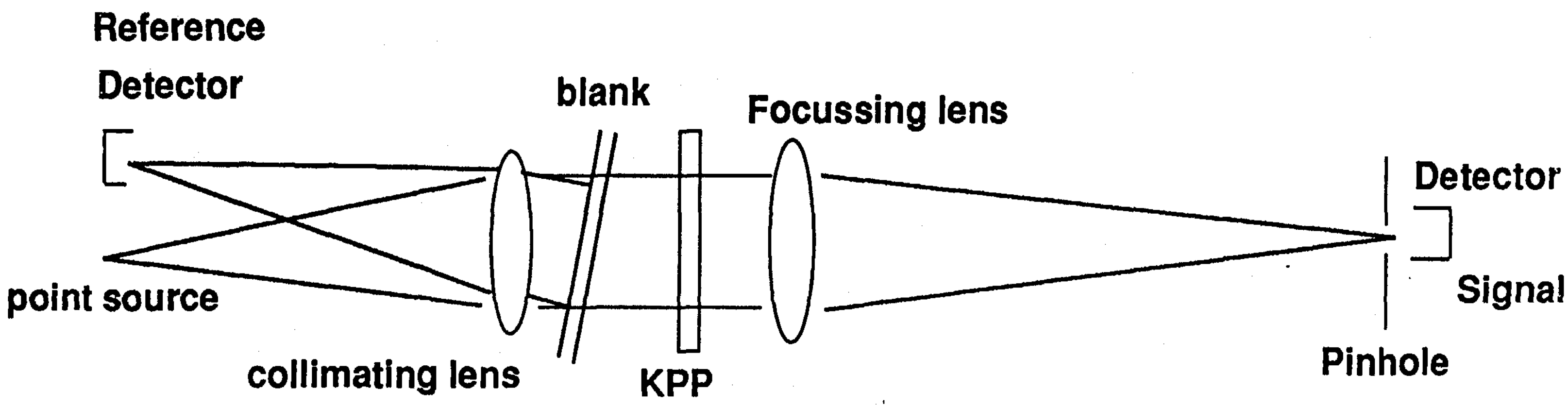
Setup for measuring the KPP efficiency



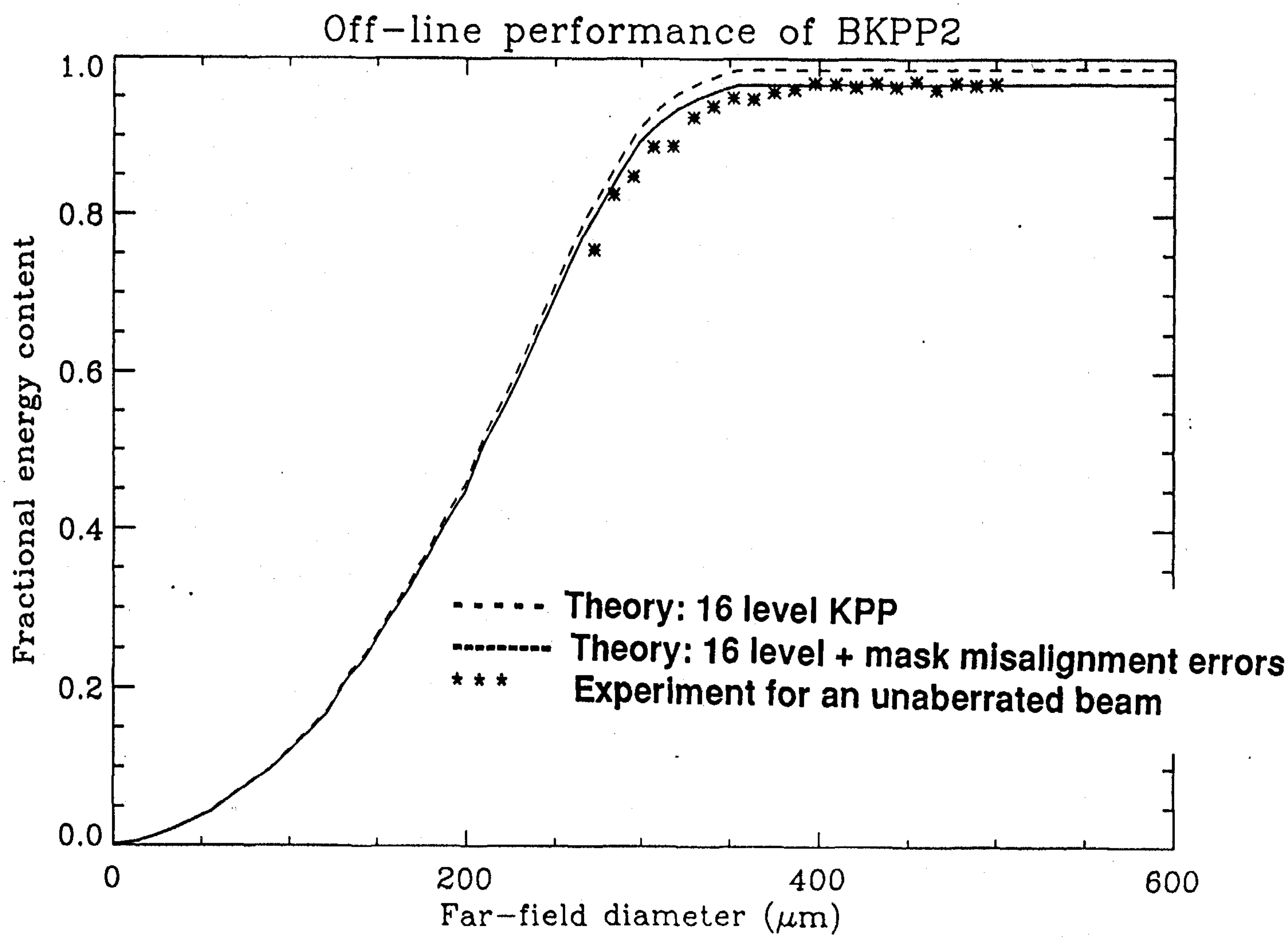
Measurements:

T1 = Signal/Reference without KPP
T2 = Signal /Reference with KPP

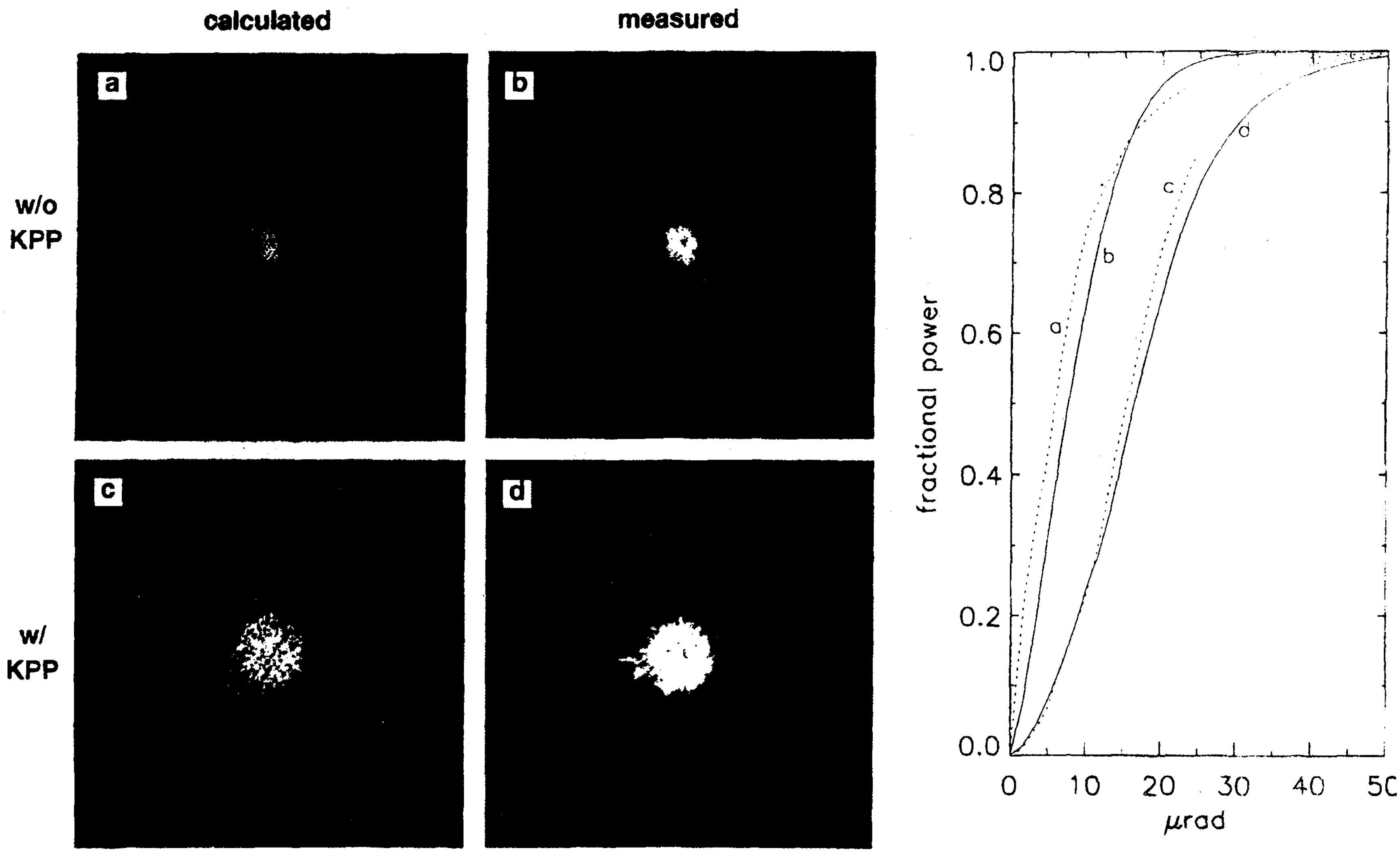
Efficiency = T2 / T1

KPP is anti-reflection coated;
Measuremetns are repeated for varying pinhole diameters

Far-field energy content for BKPP2 is in good agreement with theoretical predictions



Measured 3ω angular distributions w/ and w/o KPP are in reasonable agreement with current models



PJW BPR1 vg5.iw

Summary

- We have fabricated large aperture kinoform phase plates in fused silica substrates using lithographic approach and wet etching
- They produce fairly uniform superGaussian profiles in the far-field
- The measured efficiency (97%) of the far-field produced by the KPP is in good agreement with theoretical predictions

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