Use of Nanocrystalline Ceria in EUV Lithography Optics Polishing

Patrick G. Murray,[1] Thure Böhm[2], Holger Maltor[2]

[1] Nanophase Technologies Corporation
1319 Marquette Drive, Romeoville, IL 60446, USA
Email: pmurray@nanophase.com

[2] Carl Zeiss SMT AG
Carl Zeiss Str. 22, 73447 Oberkochen, Germany
Email: t.boehm@smt.zeiss.com

ABSTRACT

EUV lithography promises large gains in resolution as a result of the extremely short wavelength. However, the requirement of aspherical off-axis mirrors dramatically increases the challenge of the optics manufacture relative to refractive designs. For example, because of the short wavelength of only 13.5 nm, a homogenous roughness and RMS values of 2 angstroms and below are necessary for sufficient throughput and high uniformity on these parts, and these specifications can only be achieved obtained through complex polishing processes. Because of these exacting microroughness requirements, fabrication technology is being driven to the exploration of new technology areas.

An example of one of these new technology areas involves the use of nanocrystalline cerium oxide made using a patented plasma arc process that produces particles with very well defined physical properties. Because of the unique manufacturing process, these particles have highly controlled surface chemistry which results in the ability to prepare extremely stable dispersions in water. As such, these dispersion are useful in a variety of polishing processes where a small particle and a tightly controlled particle size distribution are required to access increasingly stringent surface roughness requirements.

Carl Zeiss SMT has evaluated a number of cerium oxide slurries manufactured by Nanophase Technologies Corporation for improving polishing processes. The objective was to obtain reproducible low roughness values over a wide range of spatial frequencies. Results show that a significant improvement of the surface roughness was achieved with Nanophase ceria slurry CE-6068 in all spatial frequencies.

Keywords: EUV lithography, ceria, glass polishing

1 INTRODUCTION

Compared to current wavelength changes in optical lithography, the introduction of EUVL systems will be accompanied by a large step in the resolution limit.[1] This is mainly caused by the extremely short wavelength of 13.5 nm, which has the potential to push the resolution limit by one order of magnitude. However, effectively a change by a factor of about 2-4 is achieved since the numerical aperture (NA) of EUVL systems can be expected to be in the range between 0.15 and 0.3. We expect the introduction of EUVL for the 45 nm node in process development and for the 32 nm node in volume production.

As for any lithographic system, a high contrast is required. But there is an important contrast reduction in the system which is the roughness induced flare. This is caused by the surface roughness of the individual components. The main reason for the increased importance of flare for EUVL systems is the significant wavelength reduction compared with current systems. Following the simple equation that the Total Integrated Scatter (TIS) is given by:

$$TIS = 4\pi\left(\frac{rms_{phase}}{\lambda}\right)^2 \qquad (1)$$

The same rms causes approximately two hundred times higher flare level at 13.5 nm when compared with a 193 nm system. Since the rms value given in the TIS-formula is that for the phase we have also to take into account the different behavior of mirrors and lenses when we compare both systems. The mirror has one optical surface which creates a phase rms twice as high as the surface rms.

$$rms^{mirror}{}_{phase} = 2rms_{surface} \qquad (2)$$

A lens element has two optical surfaces which contribute individually with the difference in the refractive index to the phase rms and have to be added quadratically:

$$rms^{lens}{}_{phase} = \sqrt{2}\cdot(n-1)rms_{surface} \approx 0{,}7rms_{surface} \qquad (3)$$

Consequently, the effect of a mirror element on rms is a factor of three and on flare is about a factor of 10 larger

than a conventional lens element with the same surface roughness operated at the same wavelength. In order to ensure a producible optical mirror system the number of mirrors has to be as low as possible.

Flare is the result of light scattering dominated by the roughness of optical surfaces. In this context it is useful to describe the surface topography by its Fourier decomposition, *i.e*. its power spectral density (PSD). Every frequency in the roughness profile of the mirrors will scatter in a certain solid angle. The frequency band relevant for the TIS in our discussion is defined by the field of view of the projection lens. Therefore, lower and upper cut-off frequencies can be derived. The roughness within this frequency band is usually referred to as the midspatial frequency roughness (MSFR). Lower frequencies, usually called figure, will contribute to aberrations and thereby degrade imaging fidelity, whereas frequencies beyond the high frequency cut-off - the high spatial frequency roughness - will mostly influence the reflectivity of the mirrors.

The roughness within a certain frequency band can be obtained from the integral of the PSD:

$$rms^2 = \int_{f1}^{f2}\int_{g1}^{g2} PSD(f,g)\,df\,dg \qquad (4)$$

The frequency limits for the MSFR vary from mirror to mirror depending on its position in the optical layout of the projection lens. Typically surface frequencies between 1μm and 1 mm contribute to the MSFR. The inverse quadratic dependence of the TIS with respect to the wavelength of the actinic photons restricts what can be tolerated in EUVL systems to atomic scales. Whereas in two mirror systems 0.25nm rms, corresponding roughly to the interatomic distance in solids, can be tolerated, production type, six mirror systems will call for even lower MSFR reaching down to approx. 0.1 nm rms.

Material properties as well as the chemistry of the polishing process will mainly influence the high frequency end of the MSFR whereas the low frequencies will be driven more by the geometrical properties of the aspherical mirrors and the related response of the applied fine correction processes. In this context a stable polishing slurry with well defined properties is crucial.

The challenge is to make the PSD converge simultaneously towards its specification within the whole relevant spatial frequency band, typically covering all surface structures between 10 nm and 500 nm lateral extent.

2 NANOPARTICLE CHARACTERISTICS

Nanophase Technologies Corporation produces nanocrystalline ceria in multi-ton quantities using its patented NanoArc Synthesis (NAS) technology. In the NAS process, a metal oxide precursor is vaporized in a plasma arc and the evaporated precursor is allowed to combine with a reactive gas, usually oxygen, to condense, and to form nanoparticles. Nanoparticles produced by the NAS process are equiaxed, dense, discreet single crystals.

The chemical purity of the resultant nanoparticles is extremely high because the purity of the raw materials is controlled and no by-products are produced in the NAS process. Moreover, a unique surface chemistry is imparted as a result of the “active plasma” technology; this surface chemistry enables the particles to be dispersed in water at concentrations exceeding 50-weight percent with low viscosity and Newtonian rheology at a variety of pH values. This particular particle attribute is extremely important from a slurry development point-of-view since the success or failure of a nanocrystalline material in a particular polishing application is highly dependent upon at least three factors: 1) the ability to disperse the particles down to their primary size, 2) the ability of the particle to remain fully dispersed (non-agglomerated), even under challenging polishing conditions, and 3) the ability to carefully control the particle size distribution at the time of manufacture. These factors enable an exceptionally fine surface finish to be consistently realized as a polishing process of record is developed.

3 RESULTS AND DISCUSSION

Mirrors were polished using a standard polishing process. Microroughness was measured using mico- interferometers with different magnifications (4X and 50X). Typical surface morphologies after prepolishing but before final polishing were: Sq = 0.18 nm (4x) and Sq = 0.39 nm (50X). After final polishing with Nanophase ceria slurry CE-6086 typical surface morphologies were Sq = 0.12 nm (4X) and Sq = 0.12 nm (50X), as shown in Figures 1 and 2.

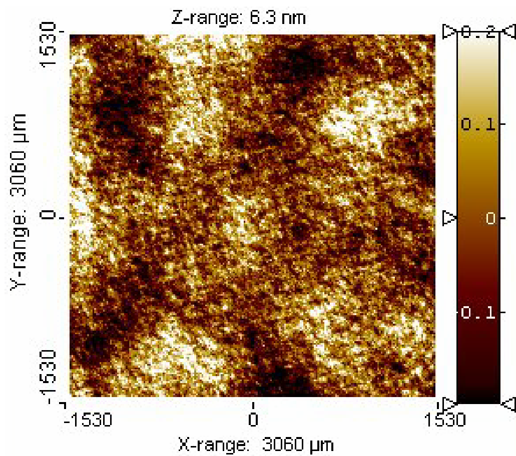

Figure 1: 4x typical surface morphology after polishing with Nanophase slurry. Sq = 0.116 nm

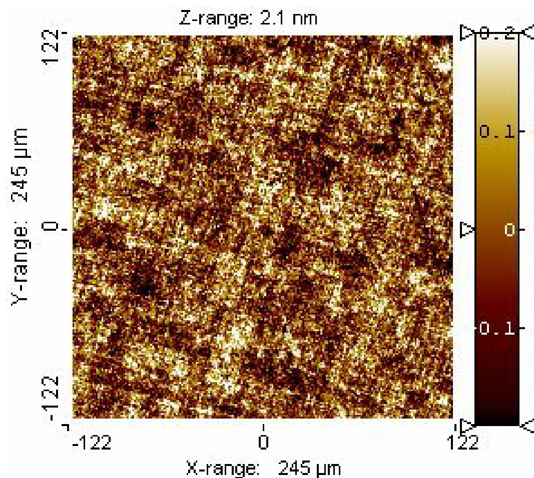

Figure 2: 50x typical surface morphology after polishing with Nanophase slurry. Sq = 0.120 nm

A significant reduction of microroughness, especially in the 50X range, was observed for Nanophase slurries CE-6042 and CE-6068. The improvement occurred after relatively short times of 20 – 40 minutes.

In a PSD evaluation, a good smoothening effect, especially in the spatial wavelength range of 1 – 100 µm, was visible.

4 CONCLUSIONS

The results show that a significant improvement of the surface roughness was achieved with Nanophase ceria slurry CE-6068 in all spatial frequencies. Improvement was especially distinct in the 50X spatial frequency range. Results are encouraging, further tests and an optimization of polishing parameters for Nanophase slurries are planned.

REFERENCES

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