Optical Problems of Wafer Inspection in DUV-Microscopy for Structures of about 0.1µm

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Abstract

The inspection of small micro and nano structures implicates the optical imaging below the resolution limit. Using classical microscopes up to these regions one has to regard the three dimensional character of the considered structures and the partially coherence of the illumination light . To get an idea about the resolution limit in dependence on microscope parameters one can use the Rayleigh-criterion, which is valid for incoherent illumination only.
On the other hand in the case of inspection of lithographic generated structures one has to regard the influence of the height of the structures as well. It can be shown, that the imaging behaviour of 3D-structures is strongly different from plane objects.

The generation of small structures lower than 0.1µm is a challenge for the inspection devices as well.
The resolution limit w (Rayleigh-criterion for incoherent illumination) and the depth of focus DOF depending on wave length λ and numerical aperture NA are given by:

$$w = 0.61\frac{\lambda}{NA} \qquad (1) \qquad\qquad DOF = 0.5\frac{\lambda}{(NA)^2} \qquad (2)$$

As it is shown in table 1 it is possible to resolve structures up to 0.1µm with high numerical aperture microscopes and DUV-illumination light .
For high numerical apertures and short wavelengths the DOF is short as well.

Table 1: Dependence on resolution limit w and depth of focus DOF from wave length λ and numerical aperture NA

$\lambda = 365$ nm			$\lambda = 248$ nm			$\lambda = 193$ nm		
NA	W in µm	DOF In µm	NA	W in µm	DOF in µm	NA	W in µm	DOF in µm
0,2	1,11	4,56	0,2	0,76	3,10	0,2	0,59	2,41
0,3	0,74	2,03	0,3	0,50	1,38	0,3	0,39	1,07
0,4	0,56	1,14	0,4	0,38	0,78	0,4	0,29	0,60
0,5	0,45	0,73	0,5	0,30	0,50	0,5	0,24	0,39
0,6	0,37	0,51	0,6	0,25	0,34	0,6	0,20	0,27
0,7	0,32	0,37	0,7	0,22	0,25	0,7	0,17	0,20
0,8	0,28	0,29	0,8	0,19	0,19	0,8	0,15	0,15
0,9	0,25	0,23	0,9	0,17	0,15	0,9	0,13	0,12

Inspection microscopes using DUV-light have been developed in the last years. The problems of the interpretation of the images are the same well known from classical microscopy with visible light.
One has to consider the dependence on the coherence and one has to regard the 3-D character of the investigated structures.

The classical resolution limit given in equation (1), the so called Rayleigh criterion, is valid for incoherent illumination only. The resolution is reduced in the case of coherent an partially coherent illumination /1/.
In classical microscopy the influence of coherence is characterised by the so called coherence parameter S as the relation of the numerical apertures of the illumination and the numerical aperture of the objective

$$S = \frac{NA_{condensor}}{NA_{objective}} \qquad (3)$$

The coherence parameter S=1 corresponds to the case of incoherent illumination, S=0.5 to partially coherent illumination and S=0.2 to nearly coherent illumination.
Picture 1 shows the test-structure, consisting of 5 bars of different width (0.15µm, 0.25µm, 0.35µm) from the centre to the outer regions and of different distances between them (0.2µm and 0.3µm).

Figure 2 shows the image intensity of the test structure with an illumination wave length of 248 nm and an numerical aperture of 0.5 in dependence of the coherence parameter. In this case the central structure is not resolved . It is not visible in the case of coherent and partially coherent illumination. It is not resolved but visible as a local maximum in the case of incoherent illumination.
Figure 3 for illumination wave length of 193 nm and a numerical aperture of 0.9 show all structures resolved. One can see the characteristic dependence on the coherence parameter with the edge oscillations for coherent illumination and the clear structures for incoherent illumination.

The other problem of the inspection of small structures is the problem of their 3D character. That means the height of the structure is in the same dimension as the width. So the object can no longer considered as a plane structure as it is usual in classical microscopy.
In the literature there are different proposals regarding the propagation of light inside of the structure /2/, /3/,/4/. In all models, considering a wave guide model, considering Fresnel diffraction at the edges or considering the height causing a phase difference only- the object is no longer given by a real transmission-function only. The imaging behaviour between real or complex-structures differs in the case of aberration, also in the case of defocus strongly.
In the following calculations the reflection r of a bar is given by:

$$r = r_0 \cdot \exp\left\{ i \frac{2\pi n}{\lambda} h \right\} \qquad (4)$$

Phase jumps of $\pi/2$ are given for the heights of $\lambda/4$ and refractive index n=1(h=62 nm and h=48 nm). In the case of the resolved imaging NA=0.9, S=0.5, λ=193nm (figure 4) a positive defocus shows that the inner structure is no longer visible . On the other hand a real object-function shows a symmetric behaviour in the case if defocus (figure 5) .
Problems arise in case of the non-resolved structure as well (figure 6). Here for a positive defocus of two times of the focus depth gives rise to pseudo structures.

Summery

Since the resolution limit strongly depends on the coherence parameter in imaging of small structures near the resolution limit the influence of the coherence parameter becomes important.
Small structures produced in lithography or epitaxy methods have a remarkable height. In the sense of optical imaging theory it is not possible to consider them a real reflective structures.
Complex object structures show a different behaviour in the case of defocus. While image intensity for real object shows a symmetric decrease of intensity independent on direction of defocus, the complex object transmission yields in different image intensities in dependence on the direction of defocus.

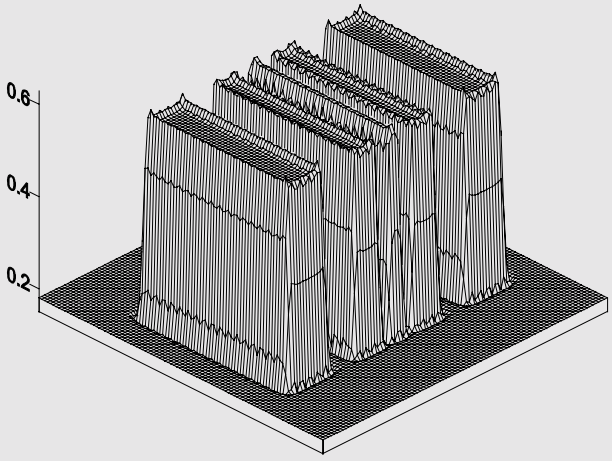
/1/ M. Born, E. Wolf, Principles of optics

/2/ R. Hild, G. Nitzsche, S. Kessler, J. Hebenstreit
Einfache Modelle zur Simulation der Abbildung 3-dimensionaler Strukturen
Optik 95 (1993), 9-15

/3/ R. Hild, G. Nitsche, U. Altenburger
The challanges of colour wafer inspection from viewpoint of partially coherent imaging theory
Microelectronic Engineering 26 (1995), 195-215

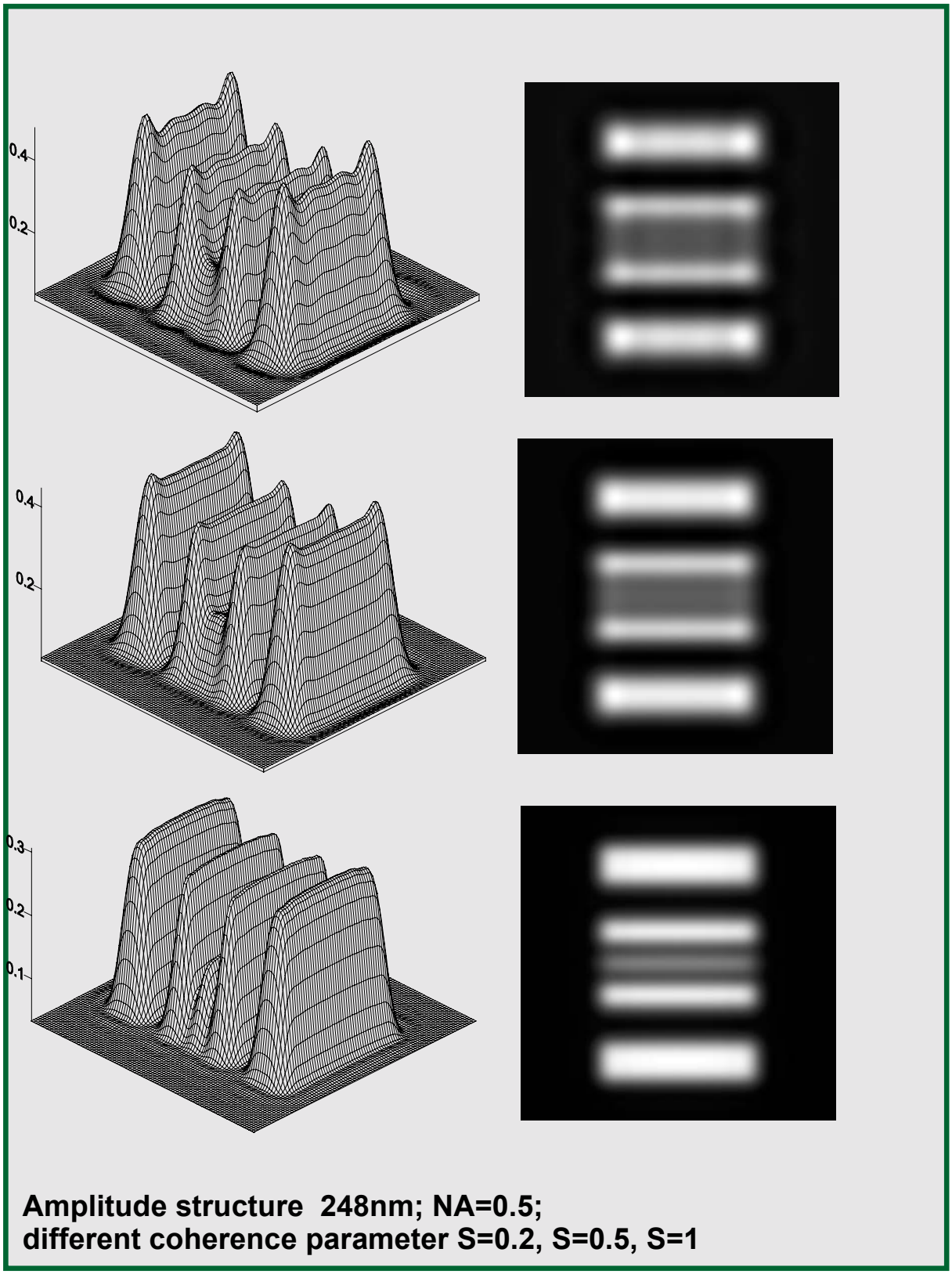
/4/ R. Hild, R. Muschall, G.Nitzsche, A. Wienecke
Investigations into the spectral behaviour of wafers and CD-measurement
MNE'95 Aix
Microelectronic Engineering 30 (1996), 583-585

Input Test Object



Test structure with growing line width between 0.15µm, 0.25µm and 0.35µm from the central to the outer parts

Figure 1


0.4
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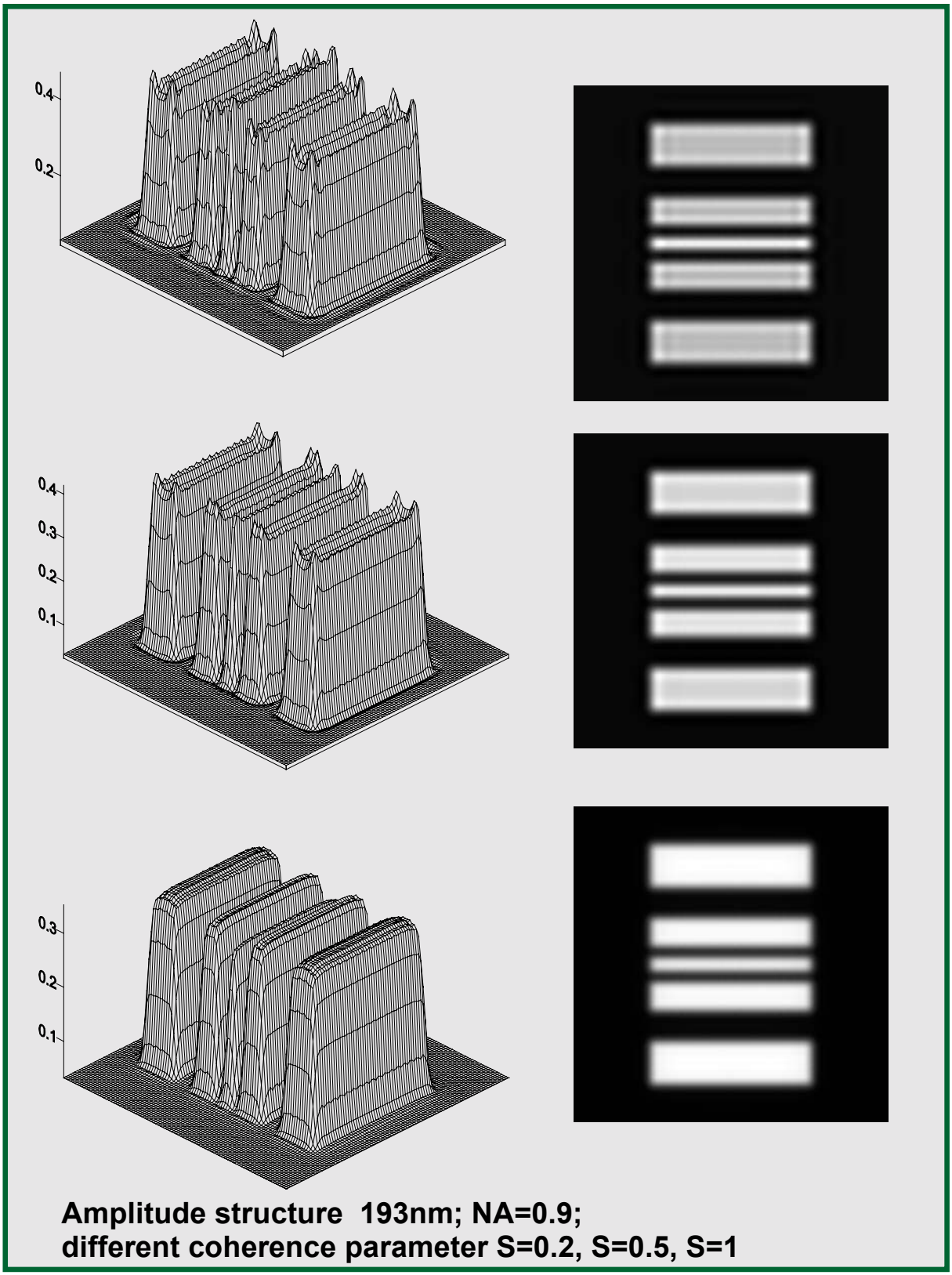
0.4
0.2
0.3
0.2
0.1
Amplitude structure 248nm; NA=0.5;
different coherence parameter S=0.2, S=0.5, S=1

Figure 2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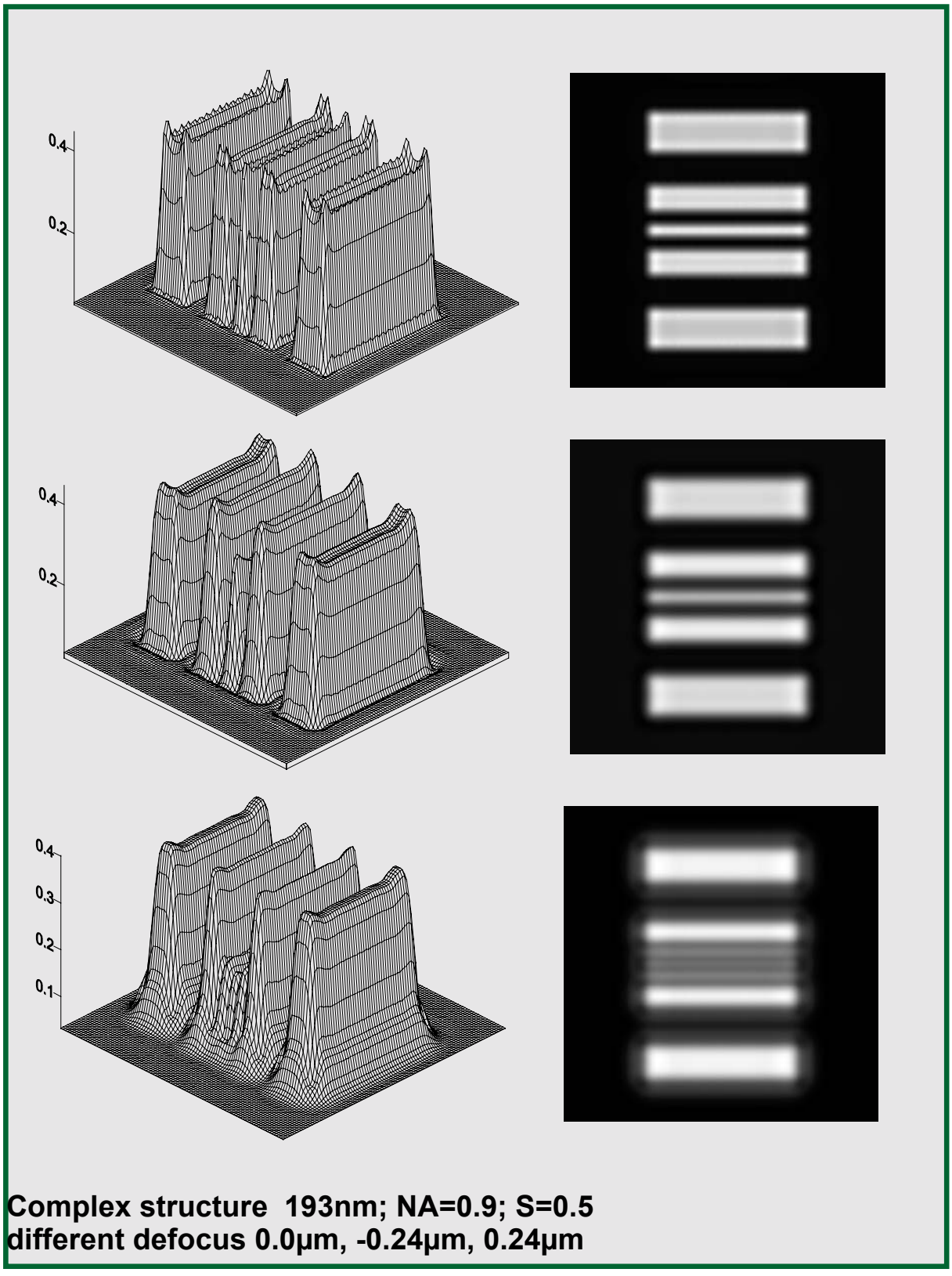
Amplitude structure 193nm; NA=0.9;
different coherence parameter S=0.2, S=0.5, S=1

Figure 3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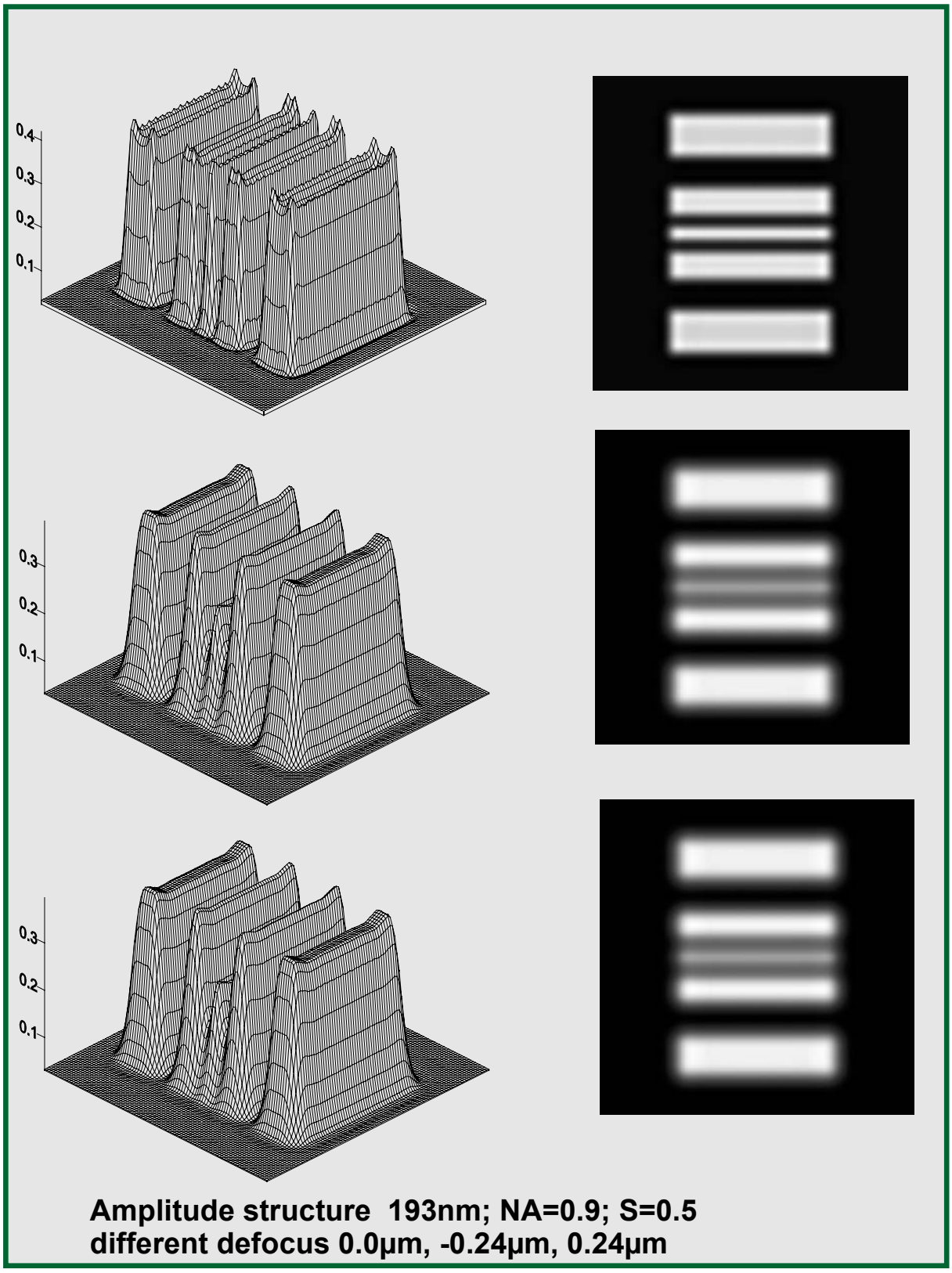
Complex structure 193nm; NA=0.9; S=0.5
different defocus 0.0µm, -0.24µm, 0.24µm

Figure 4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Amplitude structure 193nm; NA=0.9; S=0.5
different defocus 0.0µm, -0.24µm, 0.24µm

Figure 5

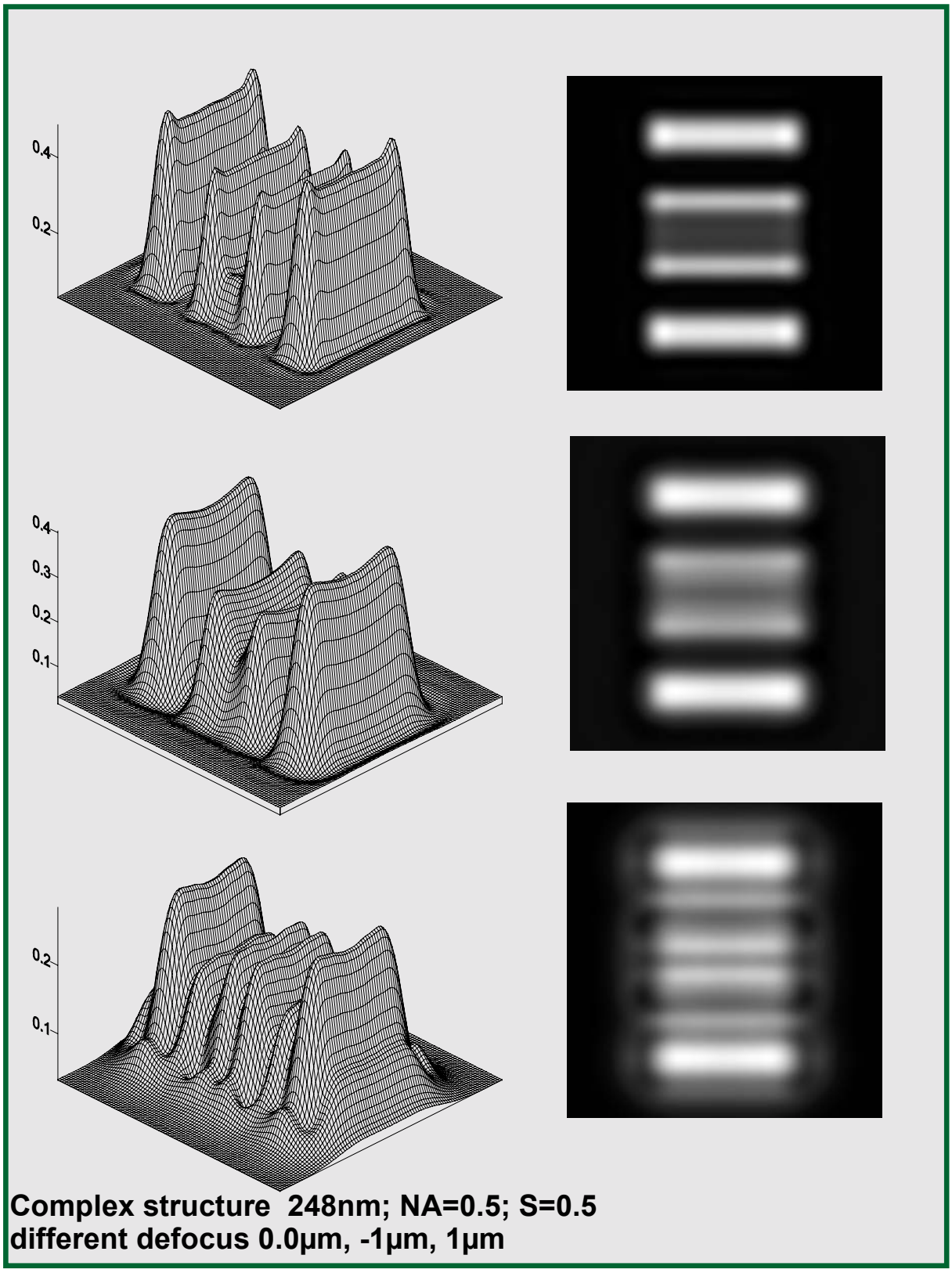
0.4
0.2
0.4
0.3
0.2
0.1
0.2
0.1
Complex structure 248nm; NA=0.5; S=0.5
different defocus 0.0µm, -1µm, 1µm

Figure 6