Raith GmbH
Hauert 18
Technologiepark
D-44227 Dortmund

Phone: +49(0)231/97 50 00-0
Fax: +49(0)231/97 50 00-5
Email: postmaster@raith.de
Internet: www.raith.com

Demo Pattern and Performance Test

For Raith Lithography Systems

0 Introduction

In order to demonstrate typical electron beam lithography applications and the performance of Raith's EBL system, Raith has generated a standard demo pattern which covers several exposure tasks within a single GdsII file. The pattern is used both for system demonstrations and for system training of new users. This report explains the pattern and its applications and shows typical exposure results. The exposure is split in 2 steps and a final inspection. Table 1 shows the approximately required time for each step.

Step	Description	Time
Exposure 1	Setup and exposure of main pattern + developing and optical inspection	~ 1 h + ~ 0.5 h
Exposure 2	Setup and exposure of overlay + developing and optical inspection	~ 0.5 h + ~ 0.5 h
SEM Inspection	Sample loading and inspection	~ 0.5 h

***Table 1**. Required basic time for complete exposure*

Additional time is required for explanations and discussion, depending on the participant's background and the feedback during the demo or training. In order to have sufficient time to discuss also the customer's applications and other general issues, we recommend to spend a full day on a system demonstration. For a system training several days are suggested, in order to give to the new user additional time for practicing.

1.1. Pattern description

Figure 1 shows the whole pattern in a working area of 900 × 900 µm^2. Several typical applications of electron beam lithography are demonstrated in the inner part of 300 × 300 µm^2. In addition, the outer part contains large contact pads and 4 global markers. The pattern is exposed in several steps using subfields (write fields) having a size of 100 × 100 µm^2 each (see dashed grey lines in figure 1). The outer contact pads are exposed with a different write field size of 300 × 300 µm^2 to demonstrate fast large area exposure as another application.

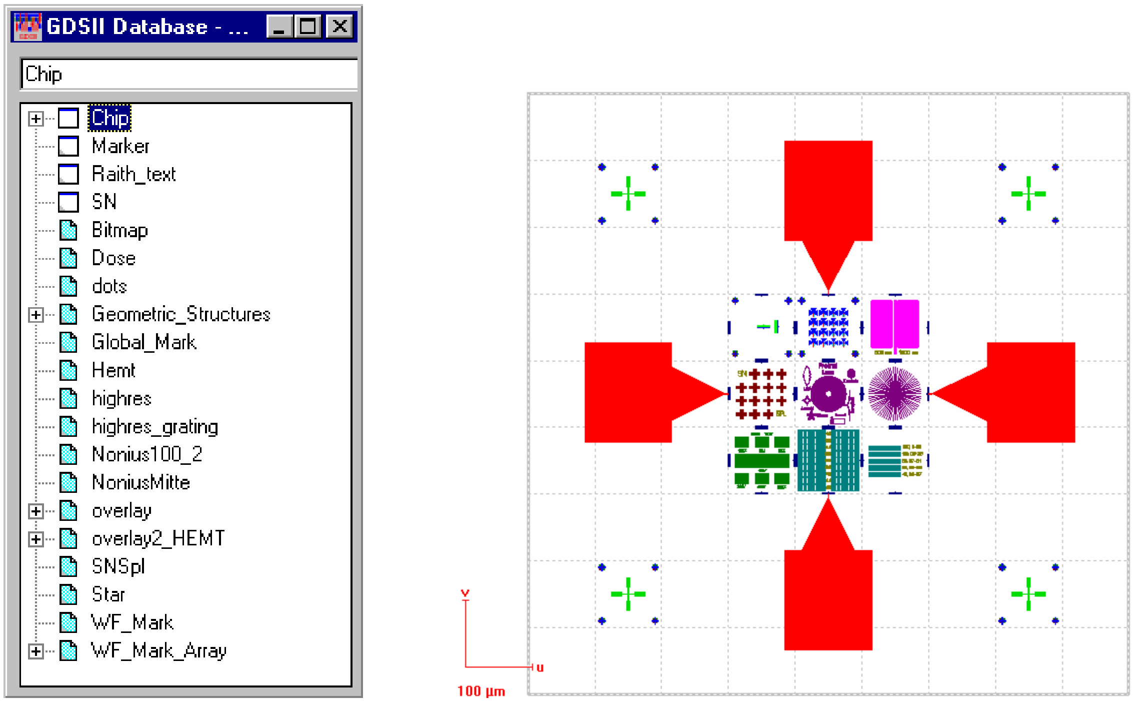

Figure 1. *GDSII data base (left) and GDSII viewer (right) with Raith Demo Pattern*

In the inner part, nine write fields are stitched together in order to demonstrate the capability of Raith´s LASER interferometer stage. The stitching error is measured by means of Vernier structures located at the write field borders. In a similar way the overlay performance is shown. The overlay pattern also consists of a Vernier structure which is exposed in two steps. During first exposure the markers and the first part of the Vernier is exposed. After developing the first part, the Vernier structure is completed in a second exposure step which uses the markers of the first step for alignment. The different applications in the inner part are explained in Figure 2 and the following text.

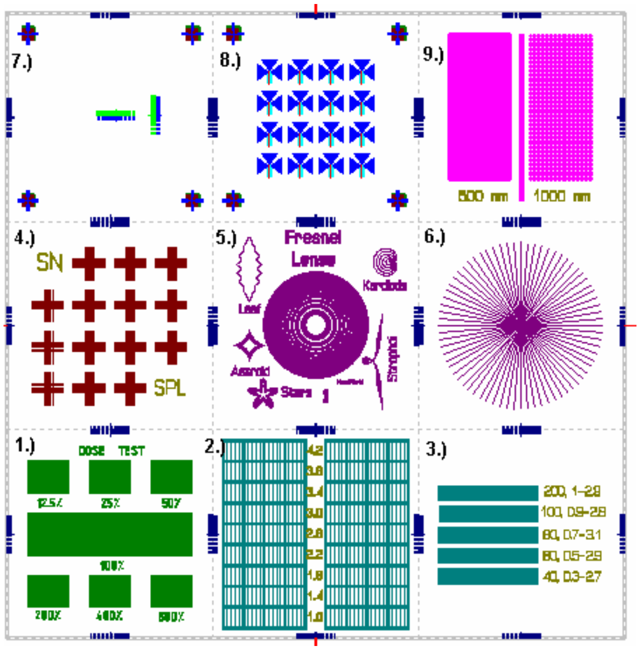

Figure 2. *Inner part of Raith Demo Pattern*

Stitch-field 1.) demonstrates the possibility to scale the **area dose** within one exposure. Stitch fields 2.) and 3.) are test patterns for **high resolution**. In field 4.) the **signal to noise** ratio in both axis is demonstrated. Field 5.) shows the exposure of **bitmaps** and of **mathematically defined structures**, including a Fresnel lense. In the 6.) stitch-field we demonstrate exposures at various angles to **check astigmatism**. In stitch-field 7.) the **overlay accuracy** after a mark registration with the Vernier pattern type is demonstrated. Field number 8.) shows another **overlay application**. Here we demonstrate overlay capabilities by exposing small gate type patterns inside a 200nm fine gap area. Pattern 9.) is a **dot array** with dose scaling to obtain circles with different diameters.

Table no.1 summarizes the different applications and their exposure time on a Raith 150 system with software version 3.0.

This table is available on request!

2. Exposure results

Figure 3 shows an overview of the exposed pattern. The global markers and the overlay structures are exposed twice, because both manual and automatic mark scans are explained during a system demonstration. Figure 4 shows an SEM image of the inner part of the pattern. The single applications within each write field are discussed in the following chapters.

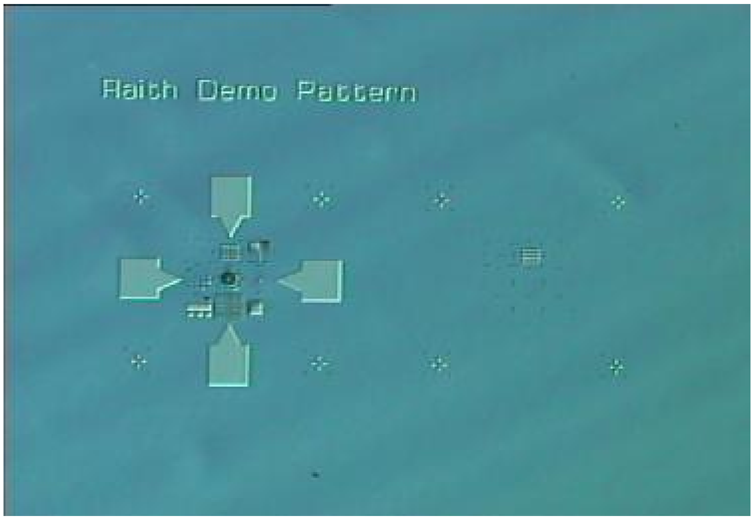

Figure 3. *Optical microscope image of total structure after development*

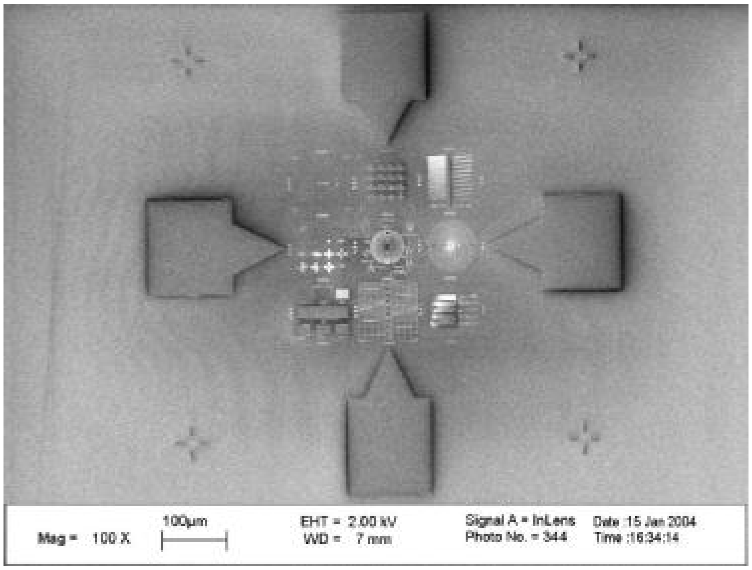

Figure 4. *SEM image of inner part of pattern no.1*

2.0. Stitching

Stitching is tested by using the vernier pattern shown in figure 5. The boxes in the two parts of the pattern have different offsets from -90 nm to 90 nm in steps of 10 nm. Thus matching boxes in the exposed pattern give the stitching error.

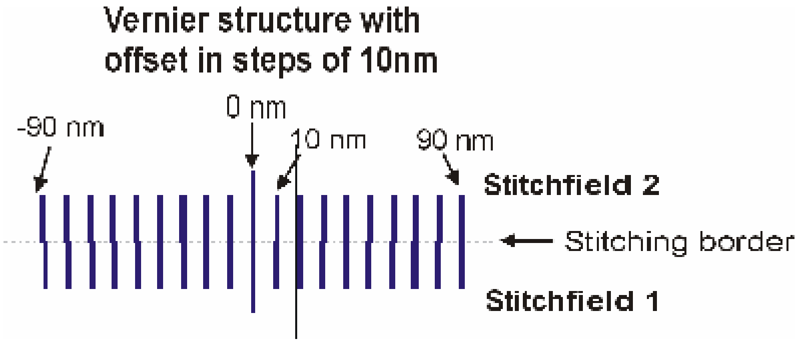

***Figure 5**. Horizontal Vernier structure used to test stitching in GdsII layout..*

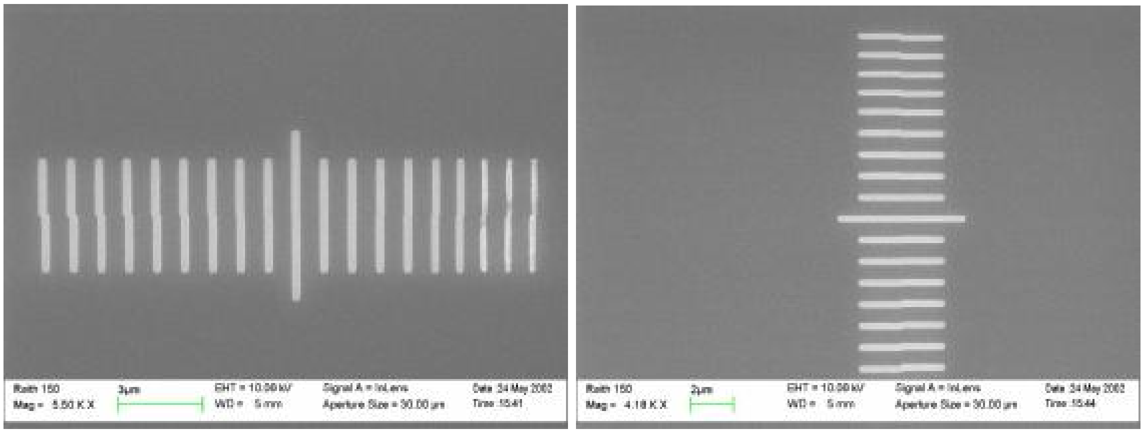

***Figure 6.** Exposed horizontal and vertical Vernier structure with perfect stitching.*

The central lines are perfectly aligned in figure 6 - indicating that no stitching error neither in x nor in y direction has been occurred during this exposure.

2.1. Dose test

The example shows underexposed structures at 12.5% dose up to an eight times overexposed rectangle. The underexposed box at 12.5% does not appear at all. On the other hand, in case of overexposure the corners of the rectangle become round. Such dose scaling can be done automatically in order to find the optimum exposure dose.

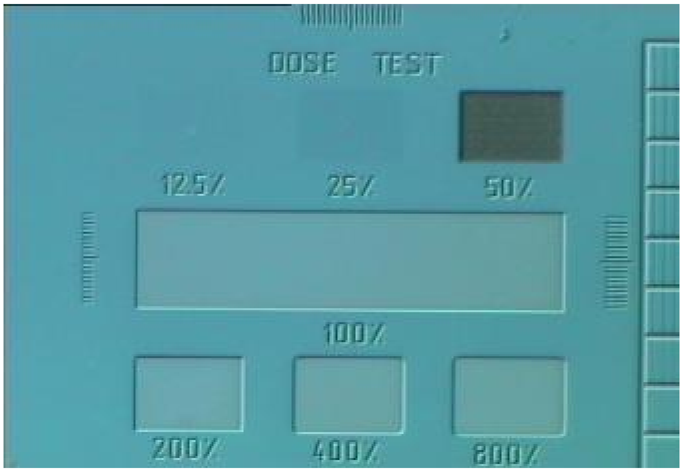

Figure 7. *Optical microscope image of stitch field no. 1.*

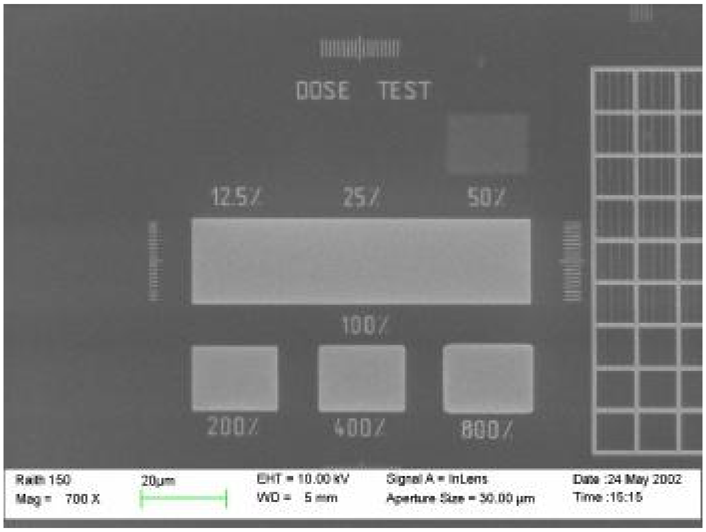

Figure 8. *SEM image of stitch field no. 1.*

2.2. High resolution test with isolated lines

Pattern 2.) contains isolated single pixel lines with a spacing of 2 µm and a dose scaling from 1.0 to 4.5 in steps of 0.1. Figure 9 shows an overview.

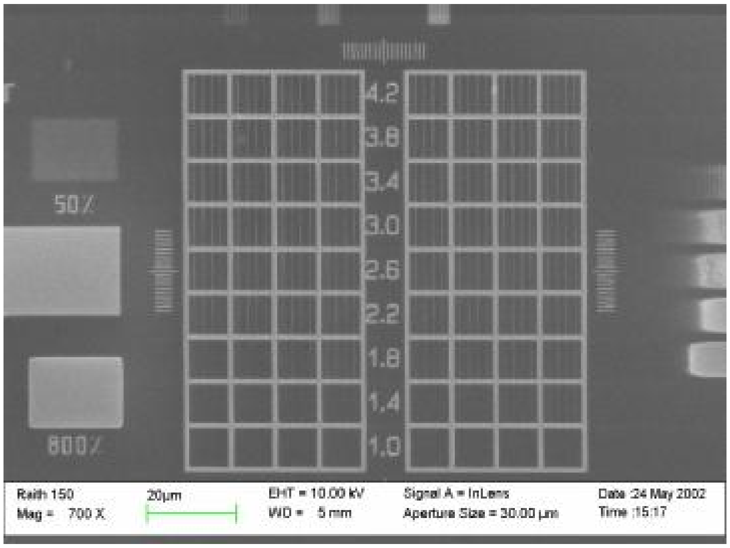

Figure 9. *SEM image of stitch field no. 2.*

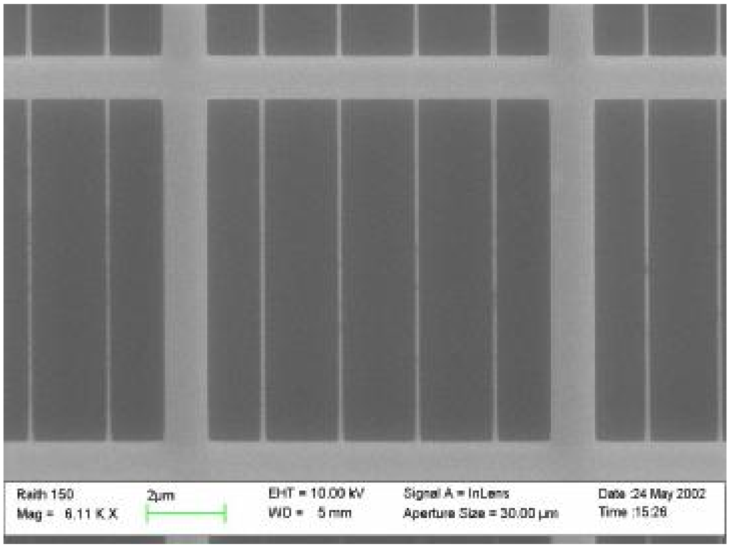

Figure 10. *SEM image of an inner part of stitch field no. 2.*

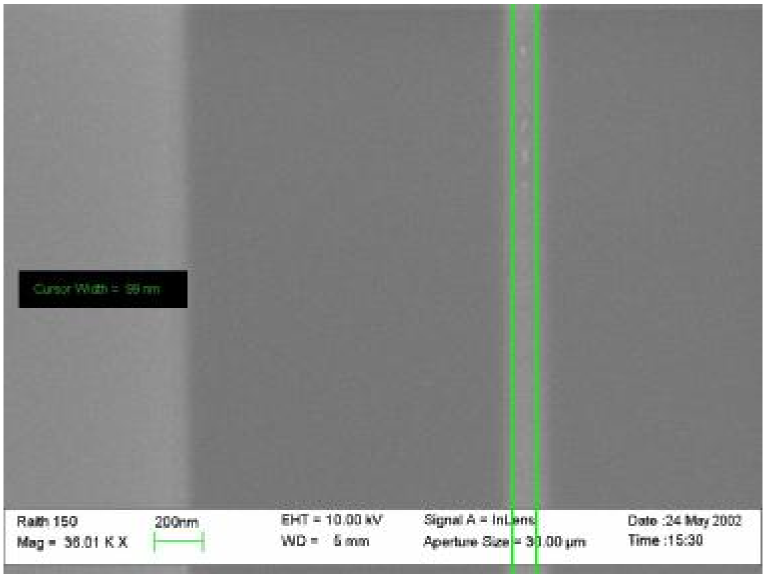

Figure 11. *Typical result for described exposure settings: 100 nm wide lines*

<u>Important Note:</u> The exposure settings of the standard demo, which is optimized to cover a lot of different applications in a reasonable time, do not yield the best possible high resolution results that can be obtained with the Raith150. For this reason, a high resolution exposure is demonstrated with other exposure settings on another sample/resist system in a second step during a demo. Please see report *Raith high resolution demo* for corresponding results.

2.3. High resolution test with gratings

Pattern 3.) contains gratings with periods of 200 nm, 100 nm, 80 nm, 60 nm, and 40 nm. The dose of the lines is continuously increased from left to right to obtain areas with equal lines and spaces as well as parts with larger lines and parts with larger spaces.

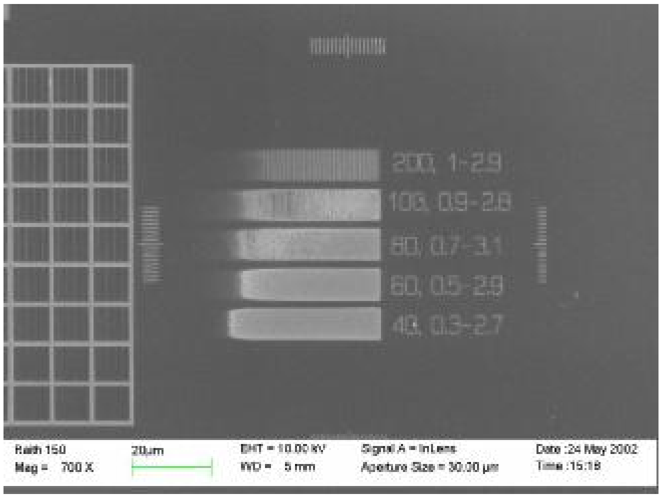

Figure 12. *SEM image of the grating exposed in stitch field no. 3.*

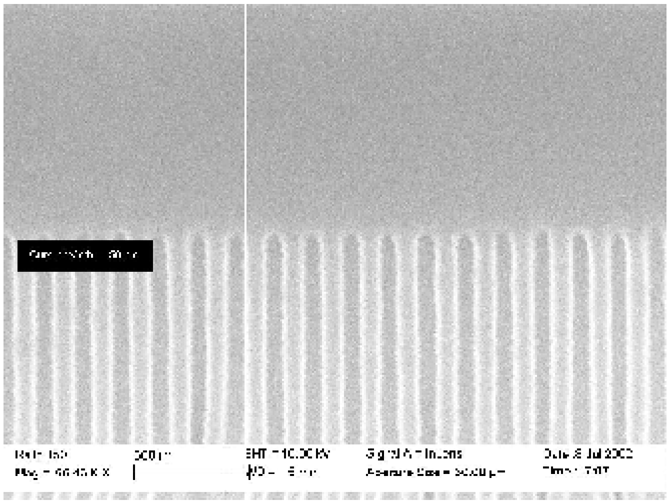

Figure 13. *Enlargement of SEM image of the grating exposed in stitch field no. 3 showing the periodic structure at 100nm pitch (50 nm lines and spaces).*

2.4. Signal-to-noise test

This pattern is used to demonstrate the signal-to-noise ratio of the pattern generator. The pattern contains several structures with crossed single pixel lines. The pitch within the structures is decreased from left to right, whereas the dose is increased from top to bottom. The obtained minimum pitch gives the signal-to-noise of the exposure. For example, the signal-to-noise ratio will be better than 1:1000, in case lines with a pitch of 200 nm (lines and spaces 100 nm) are resolved in a 100 µm write field.

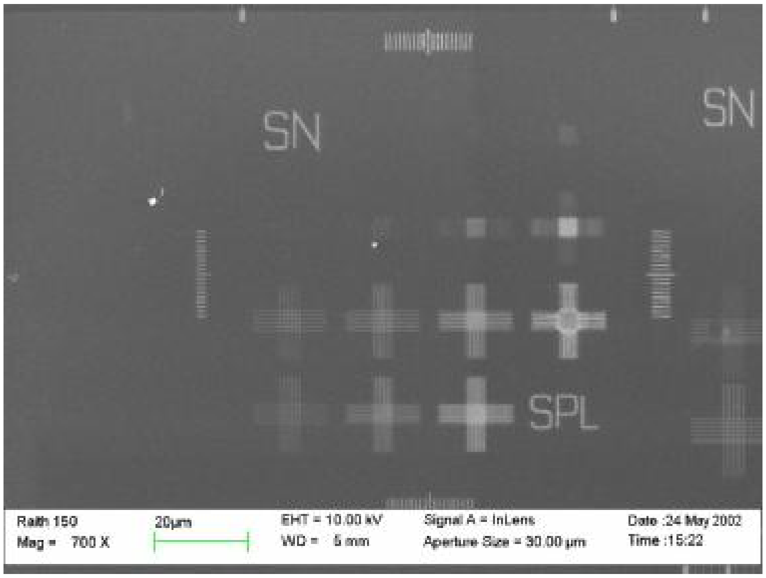

Figure 14. *SEM image of crossed single pixel lines exposed in stitch field no. 4.*

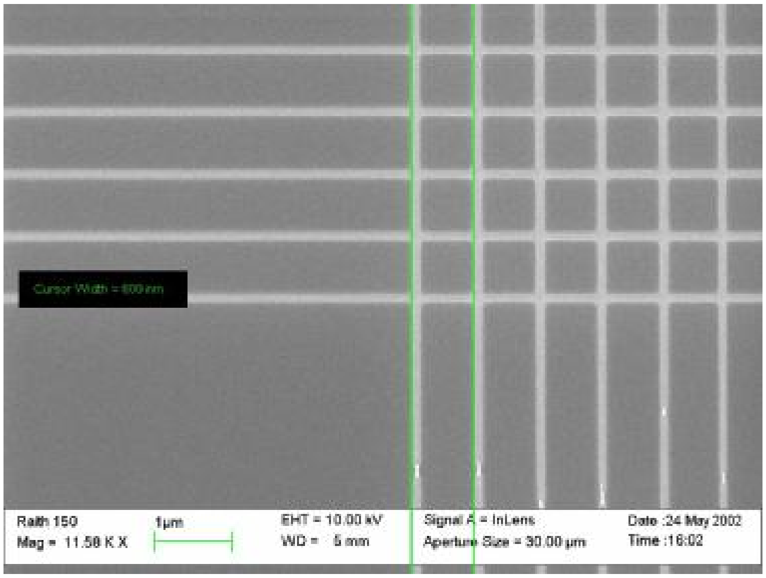

Figure 15. *Enlargement of SEM image of crossed single pixel lines exposed in stitch field no. 4.*

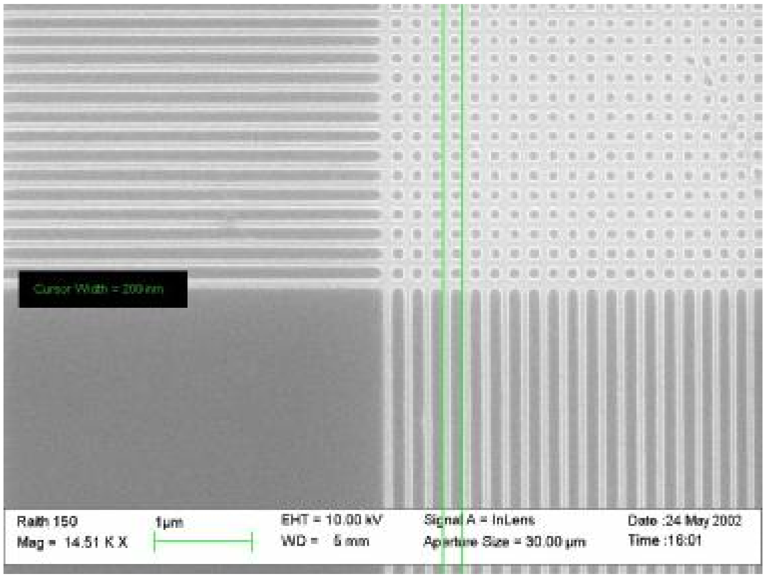

Figure 16. *Crossed single pixel lines with 200 nm pitch*

2.5. Geometric structures

Pattern 5.) shows several different applications. First, several SPL structures defined by mathematical functions are exposed. These structures have been added to the layout by the curve generator, which is included in the Raith GdsII editor. Second, the exposure of a Fresnel lense (zone plate) is demonstrated. The exposure of these rings applies the Raith circle exposure mode, which is superior to the classical approach that approximates a ring by a polygon (see additional report on circle exposure for further details). Finally, the bitmap exposure mode is demonstrated by exposing a bitmap with a world map (see figure 19).

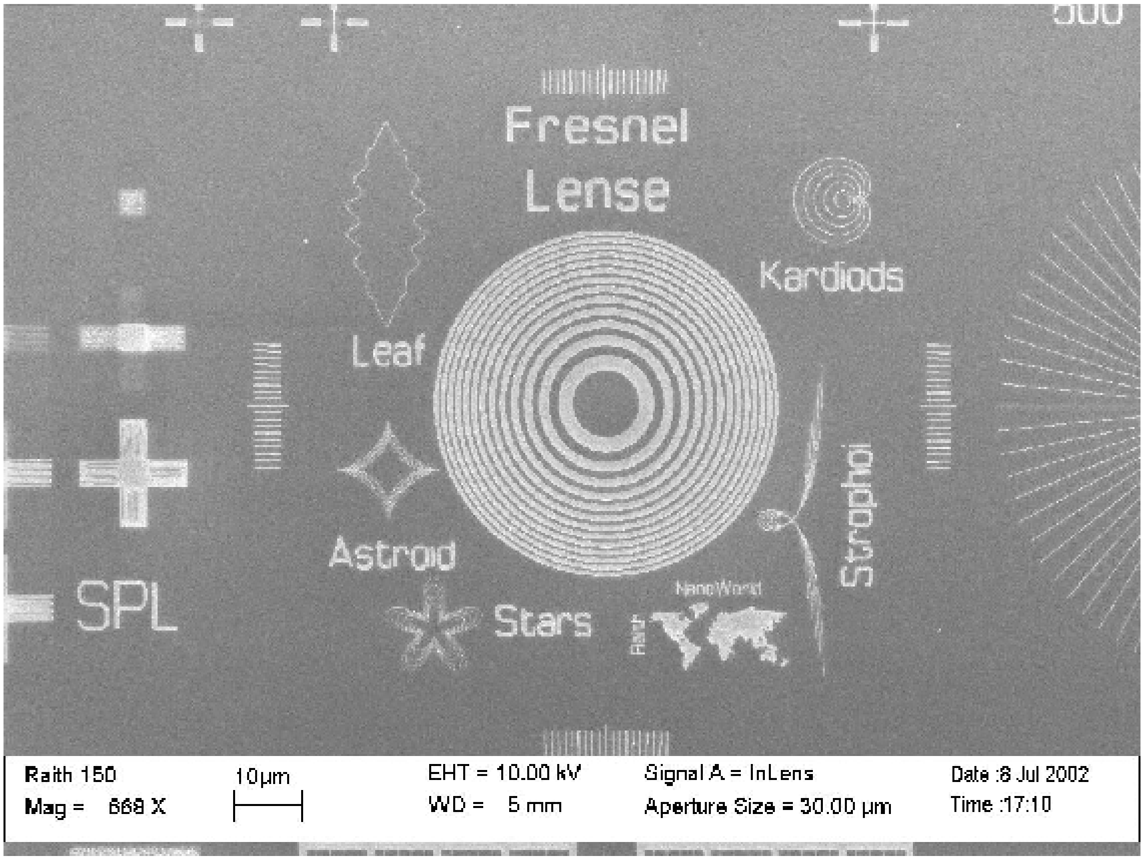

Figure 17. *SEM image of Fresnel lense and other mathematically defined structures (stitch field no.5).*

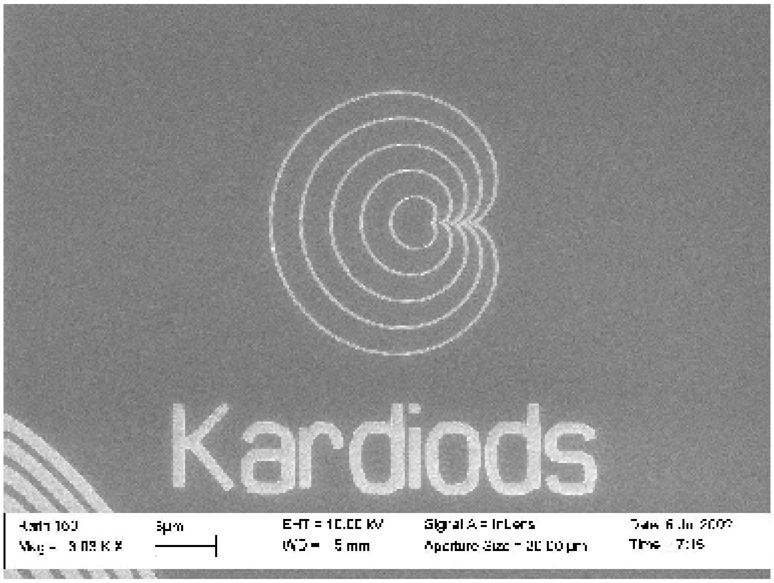

Figure 18. *Structure Kardiods, defined by a mathematical function.*

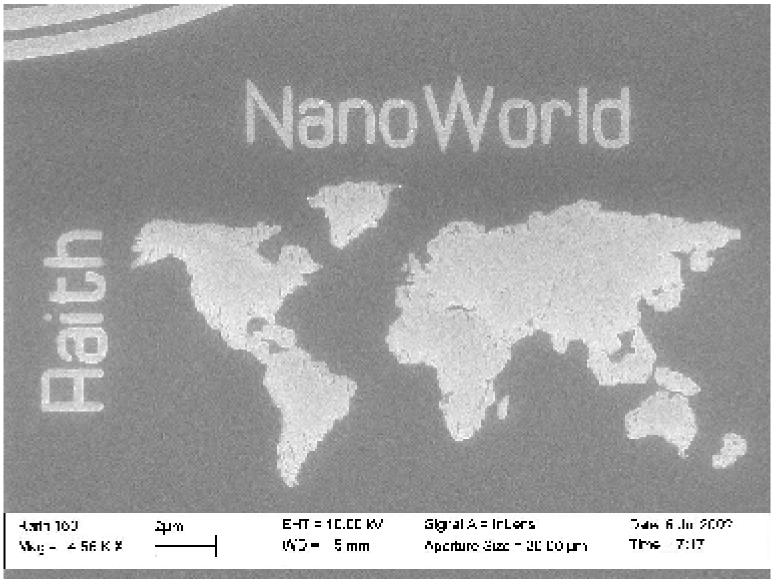

Figure 19. *Exposure of bitmaps: World map in stitch field no. 5.*

2.6. Star

Pattern 6.) contains a star with single pixel lines. This demonstrates the astigmation correction, as any astigmation error would result in variations of the line width.

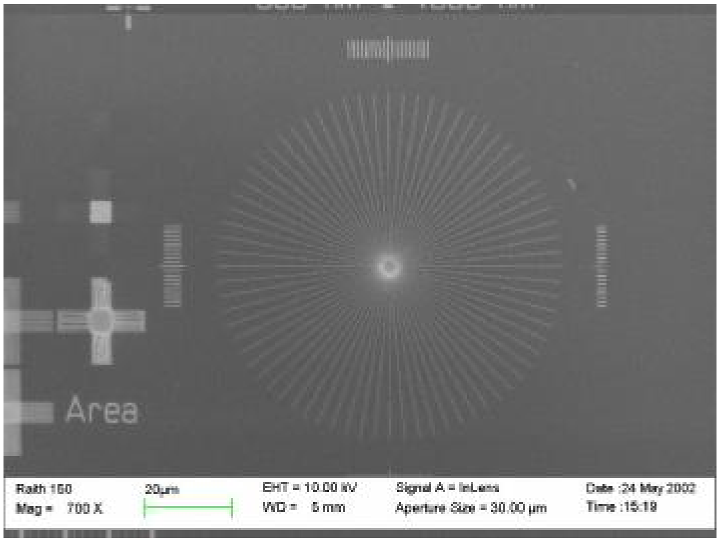

Figure 20. *SEM image of star consisting of single pixel lines (stitch field no. 6).*

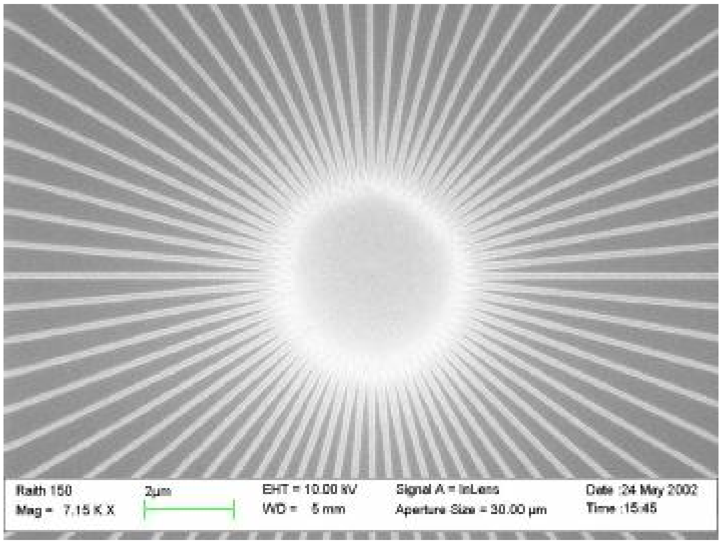

Figure 21. *Central part of star structure consisting of single pixel lines.*

2.7. Overlay

The aim of an overlay (or mix-and-match) exposure is to place a pattern into an existing structure with high accuracy. The typical placement accuracy is demonstrated in stitch field no. 7 within a two step exposure. Figure 22 shows the developed pattern with the first part of the Vernier structure after exposure step 1. The position of the local markers in the corners are measured during exposure step 2. Thereby the required offset, zoom and rotation correction for the beam is calculated and finally added by the pattern generator. Afterwards the second part of the Vernier structure is exposed. Figures 23 and 24 show a typical result with automatic mark scans. The overlay accuracy is better than 20 nm.

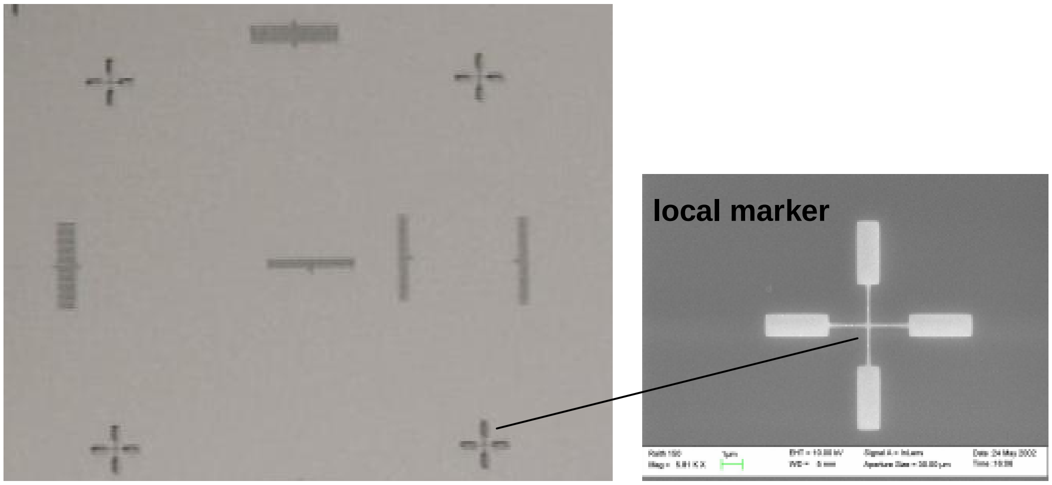

Figure 22. *Image of Vernier structure for demonstrating overlay performance after step 1 (stitch field no. 7).*

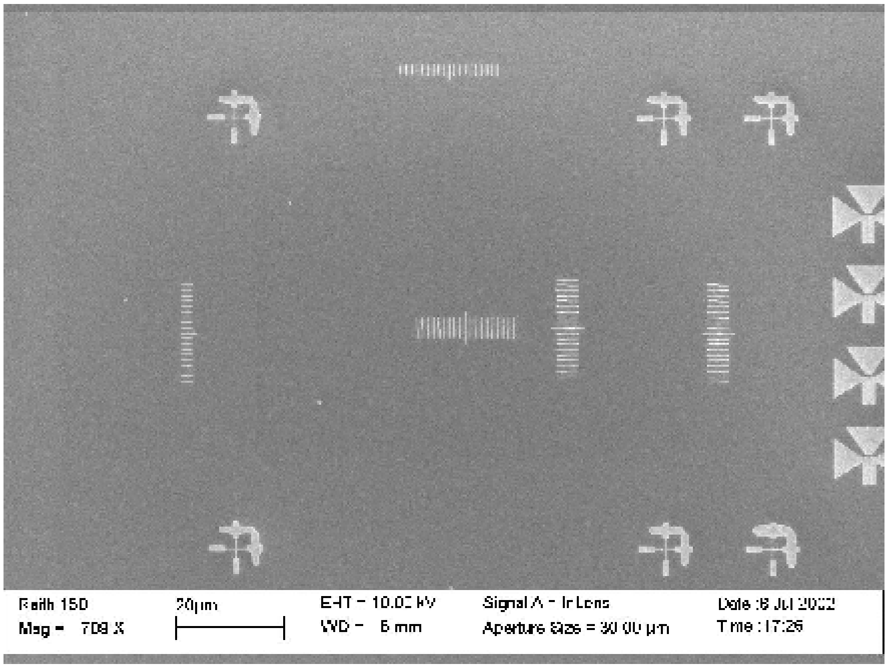

Figure 23. *SEM image of the complete Vernier structure after step 2.*

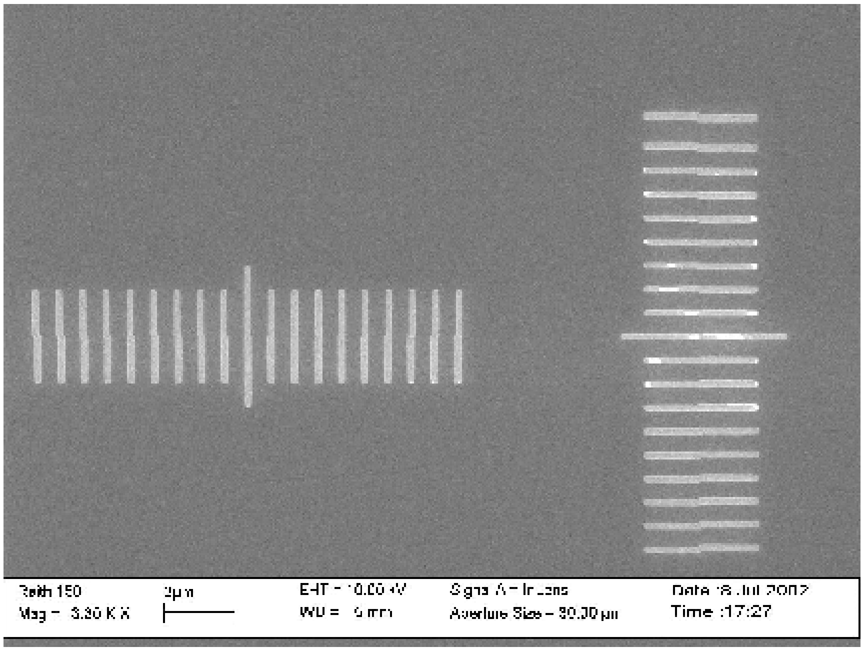

Figure 24. *Vernier structure demonstrating sub-20 nm overlay accuracy.*

2.8. HEMT

Stitch field 8.) demonstrates a typical overlay application. In the first exposure step source, drain and contact pads of 16 HEMT (high electron mobility transistor) structures and 4 markers are generated. The gap between source and drain has a width of 200 nm. The task is to place a 100 nm wide gate electrode into the centre between source and drain in the second exposure step.

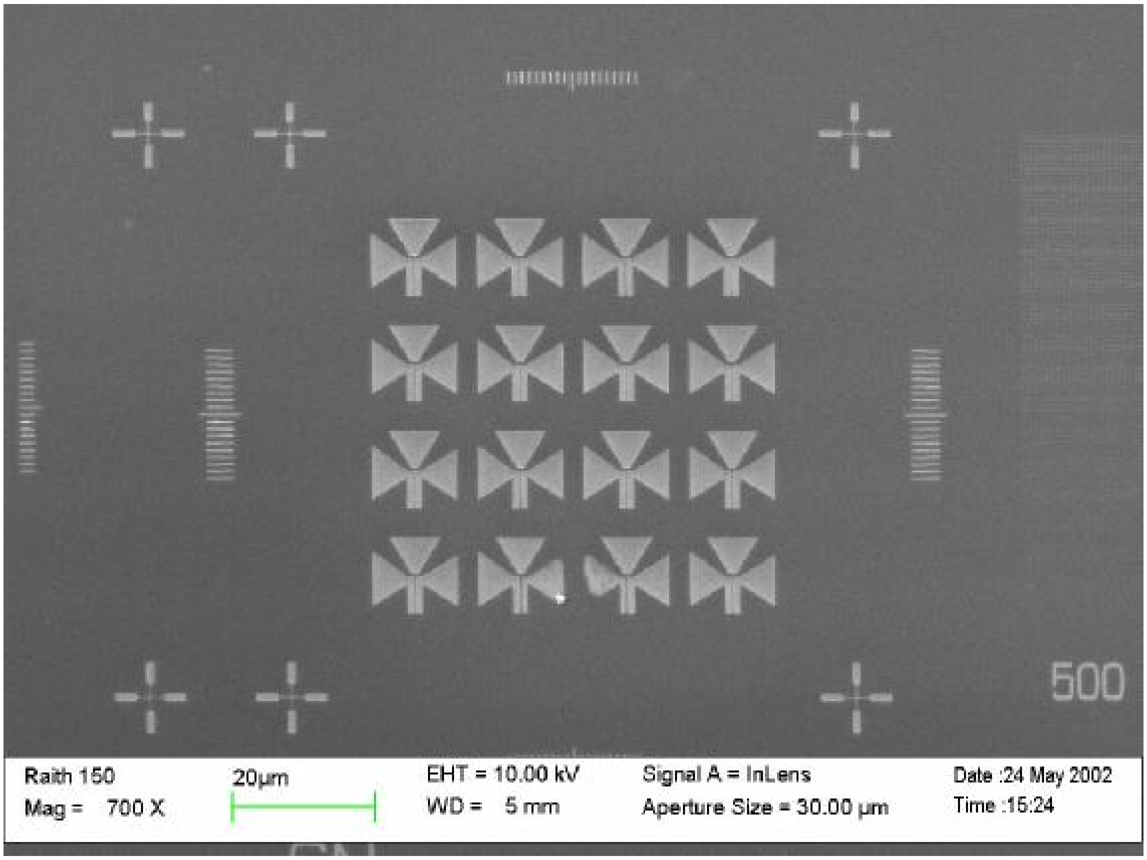

Figure 25. *SEM image of HEMT structures in stitch field no. 8.*

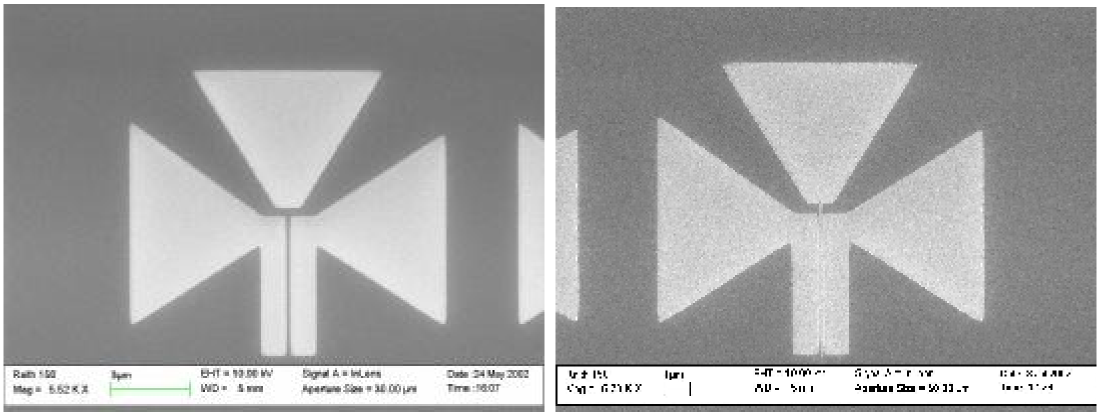

Figure 26. *SEM images of HEMT structure showing 200nm gap without gate electrode (left) and with gate electrode after the second exposure step (right).*

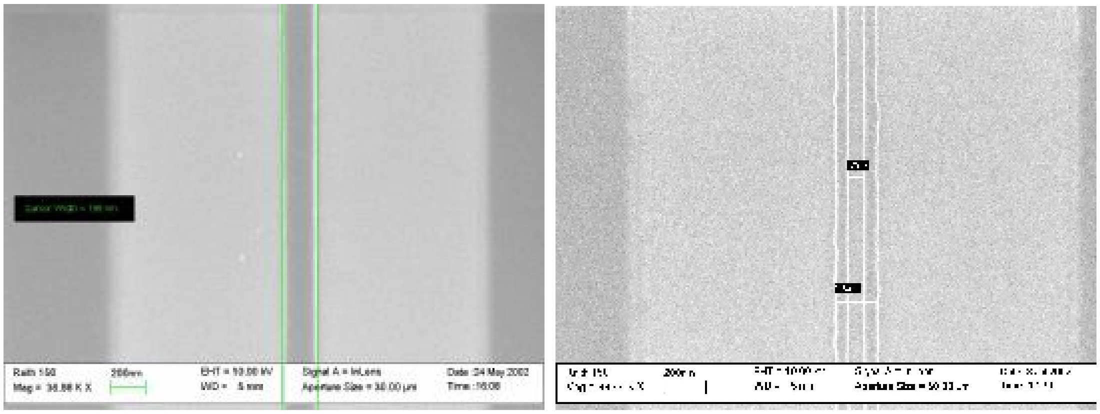

Figure 27. *SEM images of HEMT structure at higher magnification. The right image shows that the 100 nm wide gate has been exactly placed in the centre between source and drain.*

2.9. Dots

Stitch field 9.) demonstrates the fabrication of dot arrays, e.g. for the fabrication of photonic crystals. The dots are exposed as single pixels and the diameter of the resulting circles in the resist is purely controlled by the exposure time for each dot. Thereby the overall exposure time is minimized. In order to exhibit dots with different diameters, the exposed arrays have a continuous dose scaling from 0.02 to 2.8 (step 0.02) for the 500 nm pitch and 1 to 8 (step 0.1) for the 1 µm pitch.

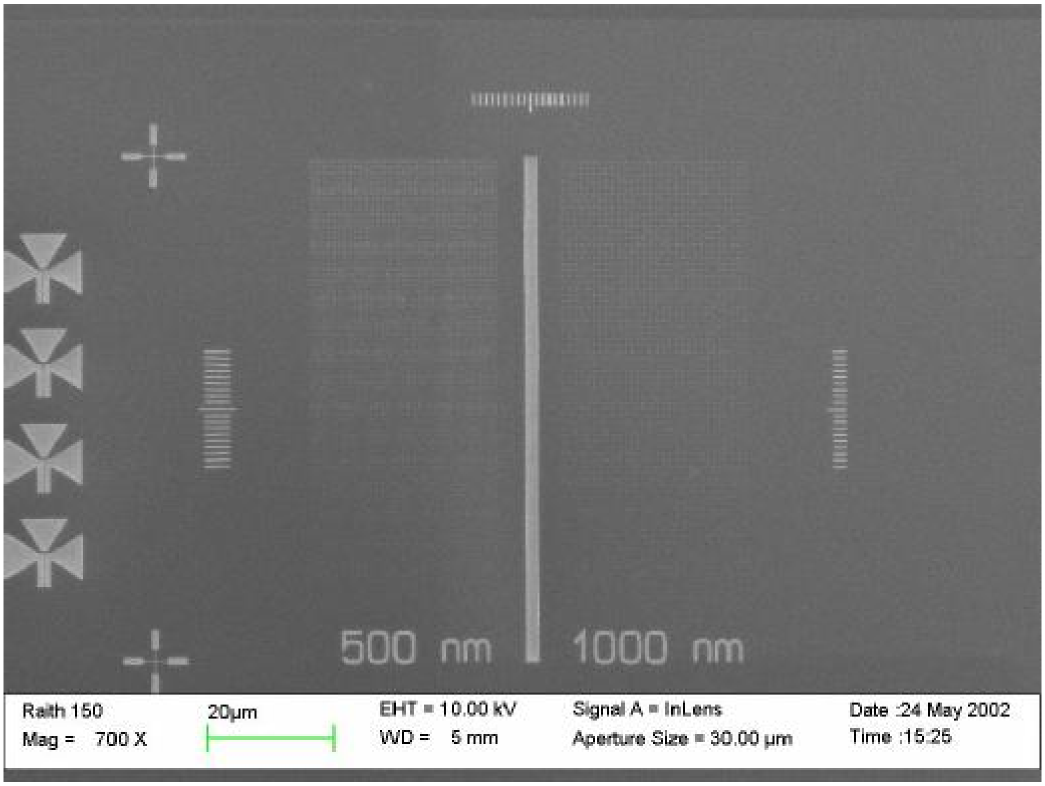

Figure 28. *SEM image of dot structure in stitch field no. 9.*

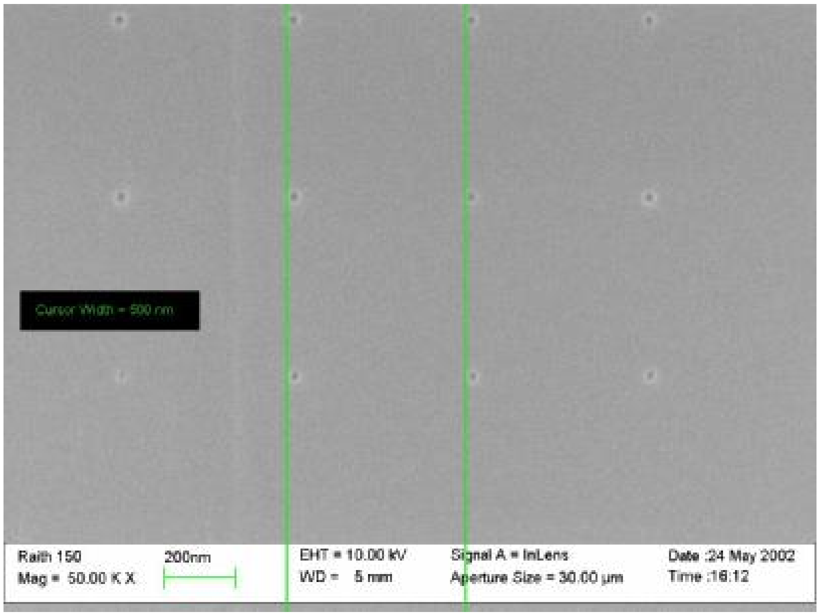

Figure 29. *SEM image of dot structure in stitch field no. 9. Distance between dots is 500 nm and diameter is less than 50 nm.*

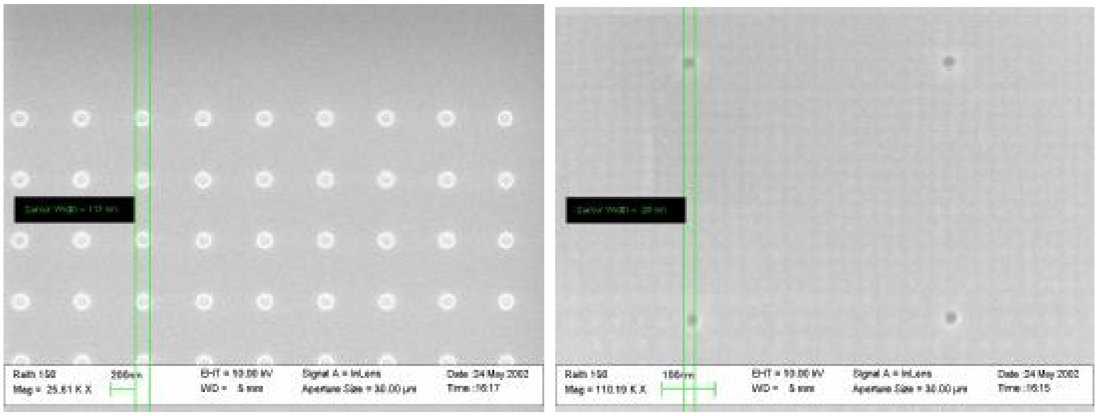

Figure 30. *SEM image of dot structure in stitch field no. 9 with dots having a diameter of about 120 nm (left) and 20 nm (right). The diameter is controlled by the exposure dose.*