Project full title: "Nanowire based Tandem Solar Cells"

Project acronym: Nano-Tandem **Grant agreement no: 641023**

Deliverable D 3.4:

Report on optimized particle patterning with redesigned master structures or processing

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Executive Summary

In this deliverable, we report on the fabrication of new master structures for which the design rules were based on experiences we gained in the Nano-Tandem project up to now. The origin for the design of the novel master structures is based on theoretical aspects concerning optimum pitch and diameter of final nanowire tandem devices as well as experimental aspects concerning the practicability of processes (interference lithography, nanoimprint lithography and epitaxy).

We fabricated large area 15 x 15 cm^2 master structures using interference lithography with a period of 1 µm and a pillar diameter of 200 nm. Furthermore, the feasibility for large area replication of these structures on 4‘‘ silicon wafers was successfully demonstrated.

Introduction and Motivation

In the Nano-Tandem project, we are following approaches leading to a deterministic growth of a regularly arranged array of III/V nanowires using templated epitaxy or leading to a stochastically orientated amount of detached III/V nanowires by the highly scalable method of aerotaxy [1]. This deliverable is focused on the deterministic templated growth of nanowires. There, also two routes are being followed within the project: (i) the growth on III/V substrates being catalysed by regularly arranged metal nanodots [2] and (ii) the template assisted selective epitaxy (TASE) approach, which allows the direct growth on silicon substrates [3].

For both routes, up-scalable processes are studied, which allow the large area patterning of metal seeds or the template structure for direct growth on silicon. For the origination of master structures we use interference lithography [4]. This technique is very well suited for the realisation of periodic features with periods down to approx. 200 nm in period. These costly master structures then shall be used as a template for stamp fabrication in order to allow replication processes. In the project, we evaluated two techniques based on soft PDMS stamps; nanoimprint lithography [5] and micro-contact printing [6]. The micro-contact printing technique was already abandoned in the project due to problems concerning resolution and reproducibility (see first periodic report).

In a joint work of University of Lund and Fraunhofer ISE (work package 6 in the Nano-Tandem project), optimum feature parameters like pitch, diameter and potential coating and contacting approaches were modelled optically [7]. There, the knowledge of the wave optical modelling of III/V nanowires from University of Lund [8] were combined with the OPTOS approach developed at Fraunhofer ISE, which allows the holistic modelling of the III/V nanowire – silicon tandem solar cell [9]. Besides these theoretical results concerning optimum parameters for the arrangement and dimensions of the III/V nanowire top-cell on a silicon bottom solar cell, also processing issues have to be taken into account when designing a new master structure (e.g. coalescence of gold nanoparticles before or during epitaxy [10]).

Taking all these aspects into account, we fabricated new large area master structures and performed first replication tests using these structures. While optical modelling indicate that optimum pattern dimensions are in the range of 500 nm for the period and even around 250 - 300 nm for the diameter of the nanowires, processing issues suggest that a larger pitch to diameter ratio is more favourable for setting up a stable process. Therefore, the focus was more placed on demonstrating a more robust process on large areas and realising a fully working device than choosing the optimum pattern parameters according to optical simulations. As a consequence we chose a pitch of 1 µm and a diameter of the features of approx. 200 nm arranged in a crossed symmetry. In the following, the redesigned master fabrication via interference lithography is described as well as first works regarding the replication of these structures.

Processing of redesigned master structures

Interference lithography

The master structures were realised on 15 x 15 cm² glass substrates. At first a so called bottom-antireflection coating (BARC) was applied using spin coating with a layer thickness of approx. 200 nm. This BARC layer is necessary to avoid standing wave effects during the coherent laser interference exposure later on. On top of this BARC layer a positive tone photoresist (AZ MIR-701) was also applied using spin coating (thickness approx. 300 nm). After softbake processes, the process of interference lithography was conducted. Applying two exposures with a sample rotation (90°) in between, leads to a crossed symmetry of the resulting pattern. The specified target diameter of approx. 200 nm was met accurately. Figure 1 shows a photograph as well as an SEM and an AFM micrograph of the fabricated large area master structures. These master structures then shall be replicated using electroplating to obtain a durable metal template as master for stamp replication for NIL. This process of electroplating is still ongoing as problems occurred in this externally conducted process (resist and BARC residues were not removable from the nickel master).

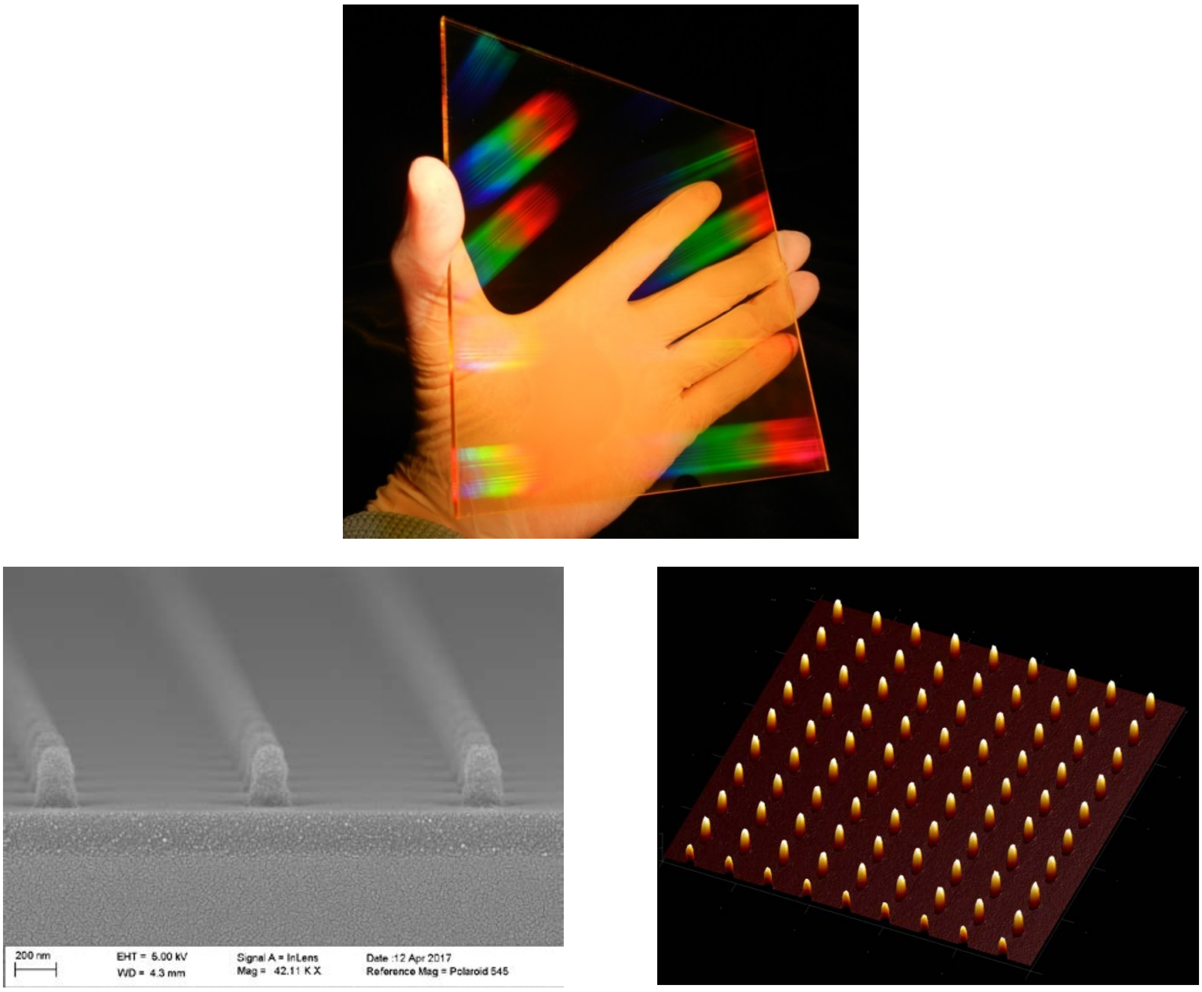

Figure 1: Images of the large area master structures newly fabricated, with design parameters being based on experiences of the Nano-Tandem project. Top: Photograph of the patterned photoresist on a 15 x 15 cm² glass substrate. Bottom: SEM (left) and AFM (right) micrographs showing the pattern dimensions of the grating (1 µm pitch, 200 nm diameter, 300 nm pattern height).

Nanoimprint Lithography (NIL)

Despite the problems in the electroplating process described before, we directly replicated PDMS stamps for NIL from one of the photoresist masters. Using these PDMS stamps and the roller-NIL tool developed at Fraunhofer ISE [11], we patterned an SU8 layer on full area on a 4’’ silicon wafer (see figure 2). As it can be seen in the SEM in figure 2 the replicated features (pillars) are a positive replica of the photoresist master shown in figure 1. Such features now will be investigated as template for the TASE process at IBM. The negative of the original master structure, i.e. a hole array, is needed for the patterning of metal catalysts for the growth on III/V substrates as conducted at University of Lund. Here, we are strongly working on the optimisation of the electroplating process in order to provide master structures in the appropriate orientation.

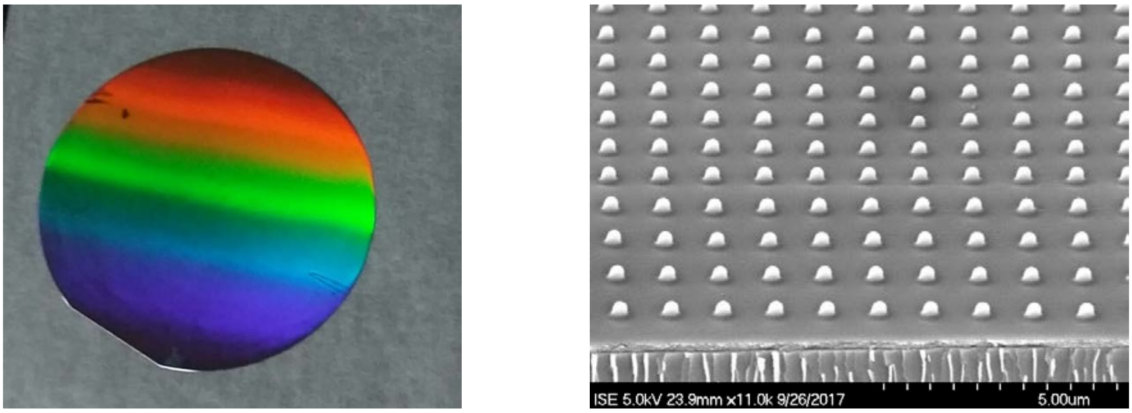

Figure 2: Photograph (left) and SEM micrograph (right) of a patterned resist layer on a 4’’ silicon wafer. The patterning was achieved using a roller-NIL process.

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