Tunable source and lens design and EBL patterning

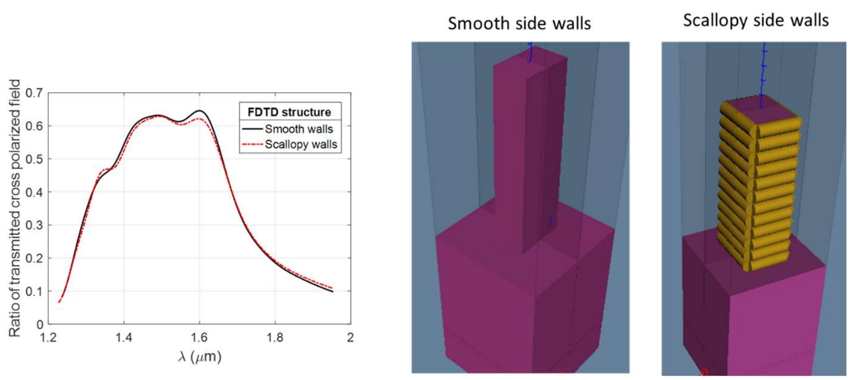
2019 Results

Activity 1.1 Tunable lens and source design: The partners involved in this activity were P1 (SINTEF) and P3 (UB).

SINTEF (P1) has:

(a) used their simulation methodology for designing metalenses for different wavelengths (using primarily internal funding prior to the project). Designs for wavelengths $\lambda = 1.55\ \mu\mathrm{m}$ have been made and fabricated (using internal funding), and initial characterization in order to develop the optical characterization setup and verify the simulations have been performed.

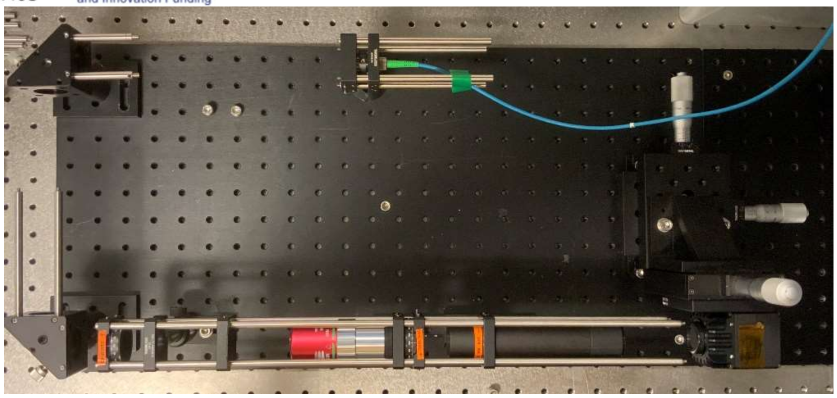
Below in Fig. 1 one observes simulations which show the optical performance of one of the metasurfaces designs which will be used in the project.



a) b)

Fig. 1. a) Finite Difference Time Domain Simulations of the ratio of transmitted cross-polarization through the infinite array of identical metamaterial structures. b) The two unit cells considered: One consisting of Si (n=3.5) with straight walls, and the other consisting of silicon covered by air-cylinders (n=1) in order to mimic the scallop surface resulting from DRIE using the Bosch process.

(b) Designed, built and tested the lens characterization setup.



For the UB (P3) the involvement in the project started with the acquisition of a new simulation program (COMSOL), and further with its testing. In this respect, several programs have been developed for analyzing the bandstructures and modes of two-dimensional periodic square arrays of cylindrical or square and rotated nanopillars. As an example, Fig. 3 illustrates the dispersion relation of the first six TE (solid line) and TM (dashed line) modes of a square array of cylindrical post with lattice constant a = 330 nm and cylinder radius 0.2a, the relative permittivity of the post in air being equal to 9. Figures 4 and 5 illustrate the absolute value of the electric field distribution in the unit cell.

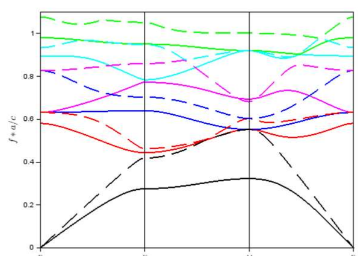
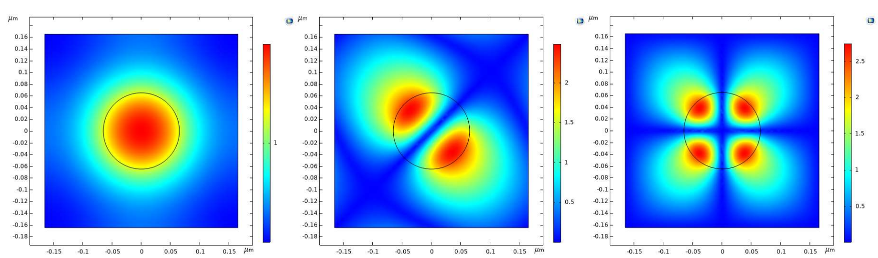
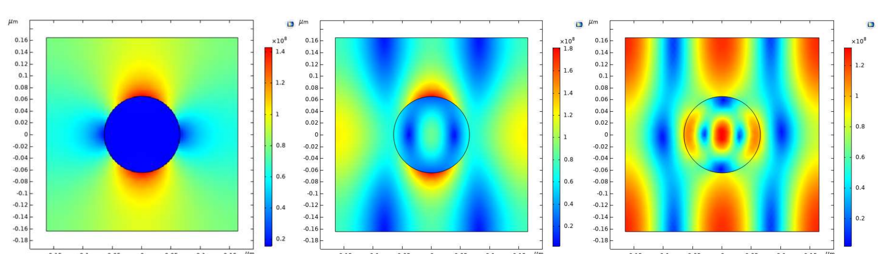


Fig.2



n = 1 *n* = 3 *n* = 6 Fig. 4



n = 1 *n* = 3 *n* = 6 Fig. 5

Searched for analytical methods for designing tunable and directional IR-emitters. The search was comprehensive and allowed identification of viable configurations involving either plasmonic architectures or all-dielectric metasurfaces.

The deliverable associated with this activity: **D1.1 –month 6 (provided on month 3):** Lens and source designs for three IR wavelengths corresponding to relevant absorption lines for the detection of plastics was fulfilled. SINTEF have provided several designs in a specific format so that the IMT (P2) can advance to the second activity of the year 2019.

Activity 1.2 EBL patterned metasurface. The IMT (P2) partner has manufactured few test structures in order to validate the proposed design consisting of repeated silicon nano-rectangles with different dimensions and rotation and to develop the nanostructuring processes.

The fabrication process of the lens structure involves the use of Electron Beam Lithography (EBL) and the Deep Reactive Ion Etching (DRIE) system as specified in the funding application. To find the initial process parameters (selection of the resist, the acceleration voltage and the dose for the EBL process, the development method, the suitable thickness of the masking films, etching parameters), IMT (P2) have proposed some test designs characterized by different types of rectangular pattern structures (diameter (D), pitch (distance between two consecutive structures –S). SEM images of the fabricated structures can be seen in Fig. 6.

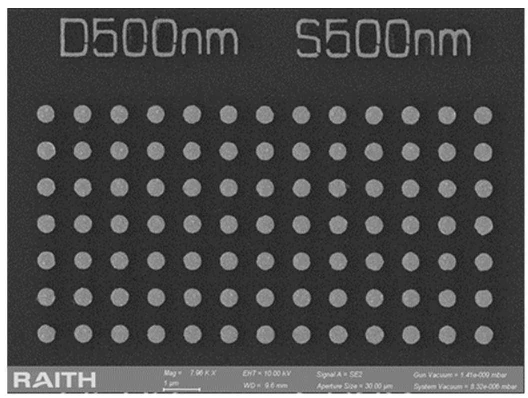


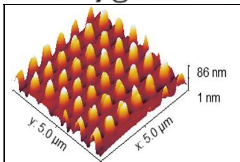
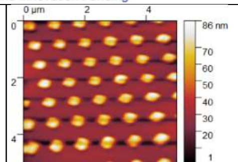
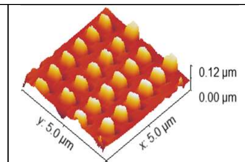
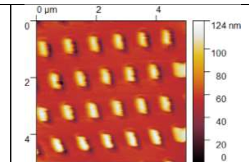
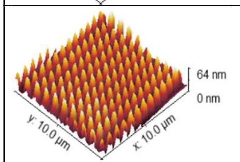
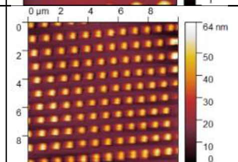
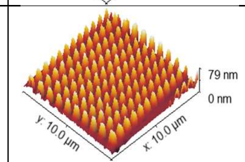
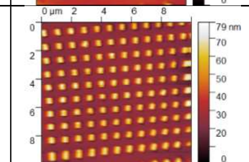
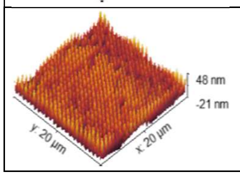
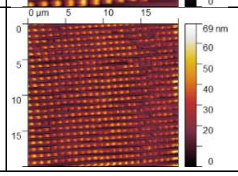
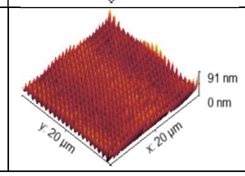
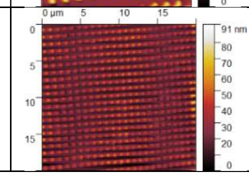
Fig. 6 SEM characterization of the obtained structures

The **deliverable D2.1 (Month 9)** was provided on **Month 6**, at the project meeting sustained in Sinaia. Both partners have provided the deliverable sooner than expected to make possible the Activity attributed to the project promoter on the 2019 year and to not change too much the initial calendar of the funding application, which should have started at March 1st.

Activity 1.3 Structural characterization of the EBL patterned metasurface: - Above are the most relevant results:

(i) AFM measurements – which can provide information about the samples' roughness expressed in terms of RMS (rough mean square) and RA (roughness average).

Sample1	RMS RA	Sample 2	RMS RA

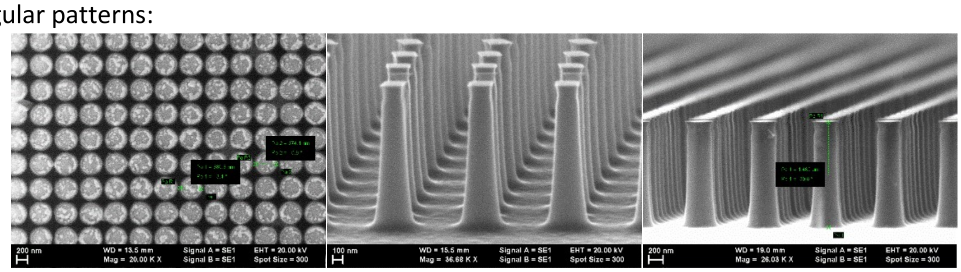
		RMS=15.6nm RA=10.7nm			RMS=16.6nm RA=10.8nm
		RMS=13.8nm RA=11nm			RMS=12.6nm RA=10.2nm
		RMS=10.4nm RA=10.7nm			RMS=10.2nm RA=8.9nm

(ii) Contact angle (CA) measurements at room temperature – which can provide information about the hydrophobicity/hydrophilicity of the realized structures. Based on the values of the measured CA, and on the characteristics of both liquids (surface tension: $\gamma_{water} = 72.8\ mN/m$; $\gamma_{diiodomethane} = 50.8\ mN/m$ and the polar (p) $\gamma_{water}^{p} = 51 mN/m$, $\gamma_{diiodomethane}^{p} = 2.3\ mN/m$) and dispersive (d) $\gamma_{water}^{d} = 21.8\ mN/m$, $\gamma_{diiodomethane}^{d} = 48.5\ mN/m$ components) the surface free energy (SFE) has been determined applying the Owens-Wendt method.

The conclusion was that the metasurfaces, depending on the quality of the obtain patterns, have the tendency to manifest a higher level of hydrophobicity in respect to the unpatterned surface of the sample.

(iii) SEM investigation:

For this report we chose three SEM pictures from which can be seen the dimensions of the rectangular patterns:



(iV) XRD measurements – the diffractograms didn't show anything else, just the diffraction plan corresponding to the 111 Si.