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Slit manufacturing and integration for the Sentinel–4 NIR and UV-VIS spectrometers

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I. ABSTRACT

The sentinel–4 spectrometer´s slits are the key components of the ultraviolet–visible (UV–VIS) and the near infrared (NIR) channels for earth observation, with absolute slit width accuracy and variation required as < 0.1 µm, respectively, and slit planarity < 0.4 µm peak to valley (P-V). Adapted lithographic structuring techniques as developed for the dry- and wet etching of silicon-on-insulator (SOI) wafers combined with special integration devices for accurate alignment as well as precision optical polishing of the mounting planes of the slit holders together with spring elements can fulfil these requirements. Protected aluminum coating ensures a light tight optical density at wavelengths between 200 nm and 1200 nm, electrical grounding, and chemical protection.

II. INTRODUCTION

The Sentinel–4 project as a part of the European Copernicus mission represents the geostationary component to monitoring the composition of the earth's atmosphere. The Sentinel–4 instrument uses a combined UV–VIS NIR spectrometer [1, 2] where a beam splitter devides the beam of light into two paths that arrive at each detector. Slits are the critical parts to generating exact deflection and reliable spectral information. The slits have to be mounted into mechanical holders that are equipped with interfaces to the beam splitter. Resulting slit assemblies must be aligned to the optical path and the detectors. The necessary slit planarity is strongly defined by the planarity of the mounting plane in the slit holders.
The paper describes the overall slit manufacturing process as the result of extensive technology development, with a focus on compliance with the most challenging geometrical tolerances.

III. REQUIREMENTS

For Sentinel–4 the absolute slit width of approximately 40 µm is specified with an absolute width tolerance < 0.1 µm and width variation < 0.045 µm within 0.6 mm length. Slit front surface planarity is required < 0.4 µm P–V.
The slits have to be open (i.e., no transparent material can be used) and shall be light tight at wavelengths between 200 nm and 1200 nm. Slit thickness should be < 10 µm, with an absolute thickness variation < 0.5 µm.
The mechanical fixation of the slit with respect to the instrument interface has to be stable to ± 2 µm in x- and y-direction and to ± 1 µm in z-direction during mechanical and thermal loads. The z-direction is the optical axis perpendicular to the slit surface. The rotational degrees of freedoms (RotX, RotY, RotZ) have to be stable < 2 arcsec. Direct sun intrusion causing thermal loads of 130 mW should not affect slit performance, life time, or slit position. No organic materials have to be used to reach a low outgassing of less than 0.1 % total mass loss.

IV. SLIT MANUFACTURING

For the realization of the free standing slit different options based on state-of-the-art micro-fabrication technologies have been evaluated experimentally. The extremely tight requirements on the accuracy of slit width and variation in combination with the small maximum thickness sorted out pure mechanical manufacturing methods. Such requirements are currently accessible only by high resolution lithography in combination with adapted etching techniques.
For the thermal and mechanical requirements a stiff single crystal material with good thermal conductivity for the slit substrate is mandatory. Micro-electronics grade Silicon (Si) is the material of choice for the spectrometer slits, due to highest standard quality, availability, and well-established processing options. .
Options for the final slit membrane material, the etching process to micro-structuring, as well as variants to coating have been investigated. They are discussed in the following.

Slit membrane material

Four options for slit structuring have been investigated:

a) Structuring into the SiO_2 membrane of an oxidized Si-wafer,

b) Structuring into a deposited Si-layer on top of an oxidized Si-wafer,

c) Structuring into a monolithic Si-wafer,

d) Structuring into the device layer of a SOI wafer.

In option a) it turned out that the SiO_2 layer contained too much internal stress which resulted in cracks after preparation of a free-standing membrane. The stress could be substantially reduced by option b). However, even here a slight amount of remaining internal stress resulted in a measurable waviness of the membrane, violating the requirement on planarity. Option c) could finally overcome cracks and waviness. However, this option does not contain a clear separation between the front (device) and rear (substrate) sides of the slit, so control of the etching depths between the two lithographic structuring processes for the two substrate sides becomes extremly hard.

In order to overcome this difficulty of a missing etch-stop layer the use of a SOI wafer has been investigated as option d). These wafers are widely used for the fabrication of micro-electronic devices. They consist of a crystalline silicon substrate with an oxidized top layer (SiO_2) of a few micrometers thickness and a crystalline device layer bonded on top of the SiO_2-layer. The device layer should realize the slit. The substantial difference to option b) is that this layer is not deposited by a sputtering process but like the substrate consists of a single Si-crystal. Consequently, there is no residual stress in the slit layer, so the otherwise observed waviness after rear side opening will not occur. Furthermore, the crystal orientation between the substrate and the device layer can be chosen differently to those of substrate and device layers which becomes interesting with etching techniques. Here, crystal orientations of substrate and device layer were chosen as <100> and <110>, respectively.

Slit Etching techniques

Investigations into etching techniques for slit and substrate came up with the method of potassium hydroxide (KOH) wet etching as it results in the lowest roughness of the slit side walls in combination with a sufficiently high membrane thickness for mechanical stability. Wet etching stops at crystal orientation <111>, leaving parts with higher orientation unaffected. Flat and very smooth edges of the slit sidewalls can thus be achieved.

Slit manufacturing starts with the opening of the substrate side using a lithographically structured masking layer. Then this method also patterns the front side. After that both sides are etched down to the intermediate SiO_2-layer which is finally removed by hydrogen fluoride (HF) etching, Figure 1.
The slit quality was found to be excellent with a very low side-wall roughness of the edges. The SiO_2 etch-stop layer ensures a good control of the etching depths for both sides.

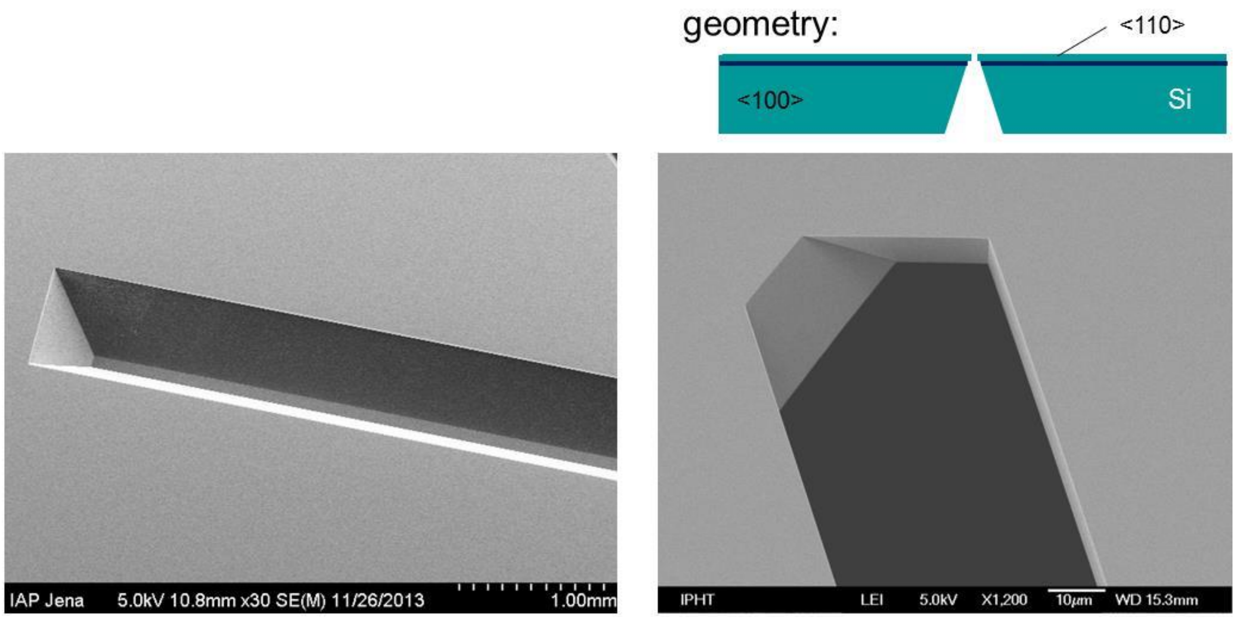

Figure 1: Slit manufactured in a <100>/<110> SOI wafer. Left: substrate (rear) side before removal of the SiO_2 etch stop between substrate and device layer. Right: slit (front) side in the device layer.

The etching method as chosen for the device layer is well adapted also to patterning Si layers of similar thickness. In the current case the device layer was specified to the maximum possible thickness (10µm), in order to ensure sufficient mechanical stiffness that avoids deformations due to residual stress. This was proven by a profilometric characterization of the slit front side after the structuring process, Figure 2.

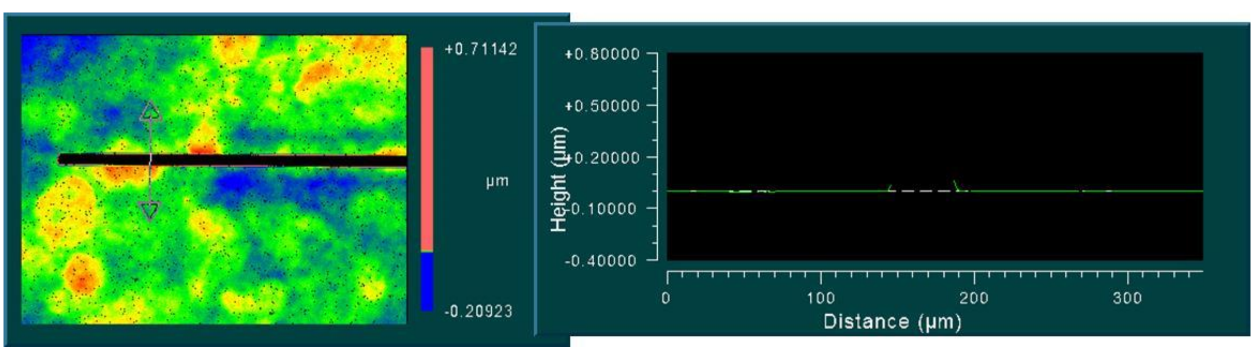

Figure 2: White light interferometric characterization of slit planarity after structuring. The image was taken on an area of approximately 1200 µm x 800 µm near the end of the slit. The cross section of the height profile shows no structuring-induced surface deformation (except of a measurement artefact near the slit edge).

Slit Coating

The requirement for light tightness up to a wavelength of 1200 nm needs additional coating on top of the slit membrane. The membrane itself is too thin to ensure this requirement. Furthermore, Si becomes transparent for wavelengths >1100 nm.

Protected aluminum and silver coatings have been investigated. Both combine a pure coating of the respective metal with a thin (about 20 nm) SiO_2 layer on top. This layer protects the metal from being affected by environmental chemicals which might degrade its optical performance in long term usage.
While optical performance and long term usage capabilities are comparable for both metals the coating with aluminum exhibits lower internal stress as compared to silver. Therefore protected aluminum coating has been chosen, in order to minimize the risk for a layer-induced bending of the slit membrane.

V. MECHANICAL PARTS DESIGN

The structured slits are mounted into mechanical holders and fixed by a mechanical frame. An elastic spring element guarantees a constant pressing force for slit planarization and fixation, Figure 3. The holders carry mechanical interfaces to the beam splitter assembly of the Sentinel–4 instrument. In order to reach the required planarity of < 0.4 µm the slits are pressed onto a very precisely manufactured mounting plane that has a planarity < 0.2 µm. The position of the aligned slits with respect to the interface holes is evaluated by measurements using fiducial marks on mounting plane, frame and slit substrate.

Investigations into spring materials and fixation methods came up with clamping a metallic canted coil spring. The metal meets both the restriction of using of organic materials, and the outgassing requirements..

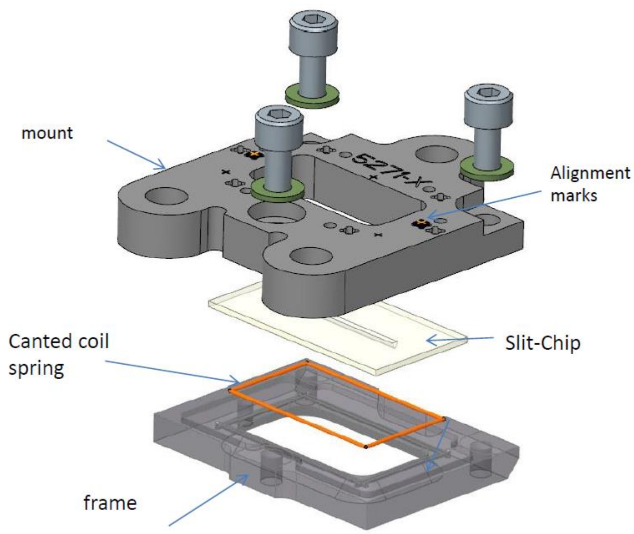

Figure 3: Components of the NIR slit assembly

The integrated and aligned slit is fixed by a two-component adhesive to prevent movement from thermal loads. The pressing force of the canted coil spring guarantees position stability < 1 µm during mechanical loads up to 100 g acceleration.
The reachable pressing force of the canted coil spring was estimated and measured to 3N. A finite element analysis calculated a slit deformation of about 60 nm in total for the mechanical loads induced by the mechanical design and a frame deformation of 380 nm as a reaction to the spring forces, Figure 4.

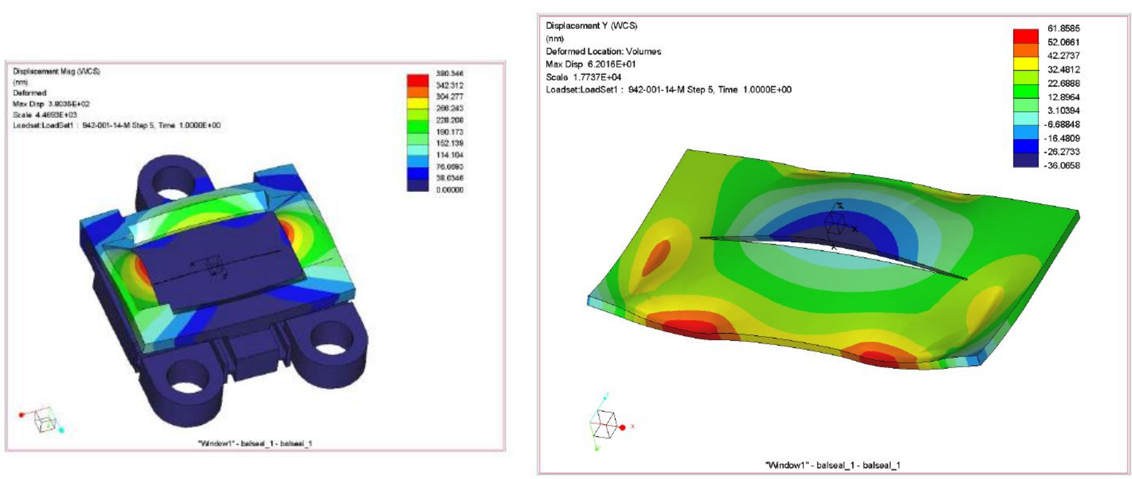

Figure 4: Finite element analyses of deformations. Left: frame. Right: slit.

VI. ASSEMBLY, INTEGRATION AND TEST OF NIR AND UV-VIS SLIT ASSEMBLIES

The assembly starts with integrating the canted coil springs into the frame by use of special V-nuts, which will fix the coils. Then the slits are centered onto the mounting plane while monitoring their position with respect to the interface holes. Then the slits are fixed by mechanical stops in order to prevent them from being replaced during frame integration. Finally, slit position and planarity are measured with an interferometer. If they meet the specification the frame is fixed by screws.

Required slit planarity < 0.4 µm is reached, Figure 5. Measured slit bending correlates with the slit deformation as calculated by the finite element analysis (Figure 4).

Planarities of most interface planes are already in the range of 1-2 µm, and the final slit deformation depends on the deformation of the slit mounting plane as a result of screw preload. Load tests show large deformations of that plane, suggesting even stricter requirements of « 2 µm on planarity of all interface planes, Figure 5.

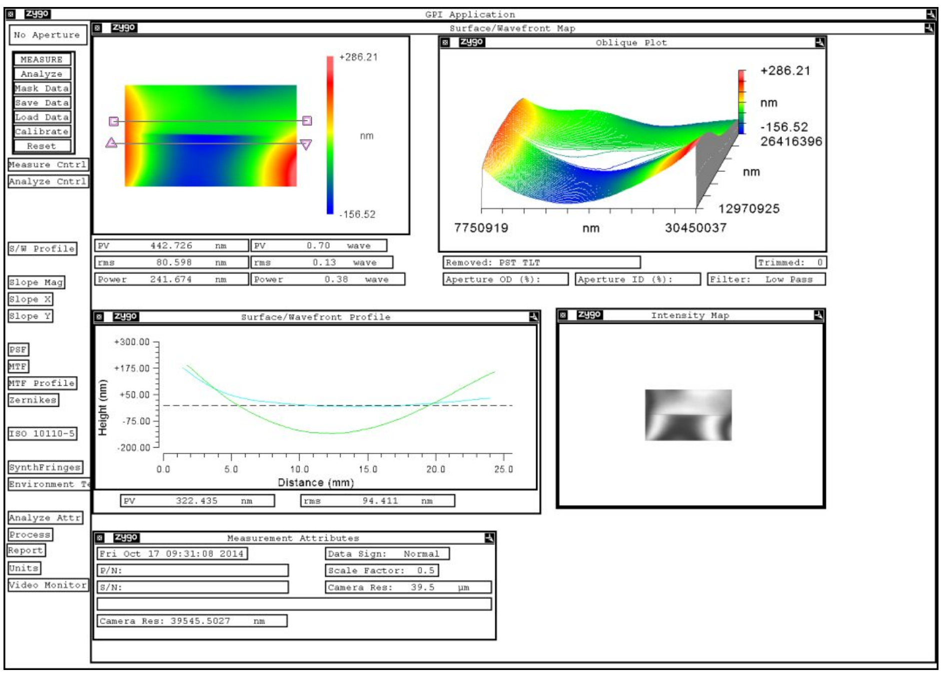

Figure 5**:** Slit planarity in the UV–VIS slit assembly.

VII. CONCLUSION

Both the NIR and UV–VIS slit assemblies (Figure 6) reach the required specifications Slit planarity depends on the planarity of the mounting plane which should be < 0.2 µm. Tests performed by Jena-Optronik GmbH show that mechanical and thermal loads will not affect the performance of the integrated slits. However, torque tests of the higher-level beam splitter assembly found that planarities < 0.2 µm are required for all interface planes including the NIR and UV–VIS slit assemblies. Hence their re-design is currently under active consideration.

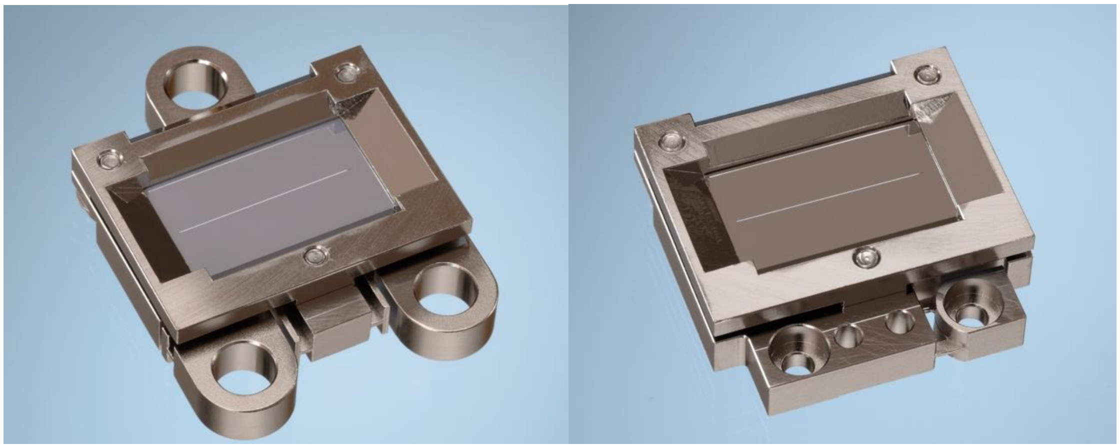

Figure 6: Final split assemblies. Left: NIR. Right: UV–VIS.

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REFERENCES

[1] https://directory.eoportal.org/web/eoportal/satellite-missions/c-missions/copernicus-sentinel-4

[2] Hendrik R. Stark, Hermann Ludwig Möller, Grégory Bazalgette Courrèges-Lacoste, Rob Koopman, Silvia Mezzasoma, Ben Veihelmann (2013). "The Sentinel-4 mission, its components and its implementation". Proceedings of the Joint EUMETSAT /AMS Meteorological Satellite Conference to address issues on Weather, Climate, Oceans and the Environment, Vienna, Austria, Sept. 16-20, 2013, URL : http://www.eumetsat.int/website/wcm/idc/idcplg?IdcService=GET_FILE&dDocName=PDF_CONF_P_S1_10_STARK_V &RevisionSelectionMethod=LatestReleased&Rendition=Web