Executive Summary Report

INFRA-RED LENS POLISHING FOR HIGH PERFORMANCE APPLICATIONS

asphericon s.r.o.

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1. Introduction

This document summarizes the findings of the ESA AO/1-9826/19/NL/AR project, including a brief overview of results and challenges. The infra-red lens polishing for high performance applications was initiated to evolve polishing methods for lenses used in high performance applications. The mission was to develop new polishing techniques and compare them to the currently used ones.

The research made by the European Space Agency is not only focused on the visible spectrum of radiation, but also on the infra-red spectrum of radiation. The wavelength of infra-red radiation ranges from between 0.75 µm to 1000 µm. Standard optic materials cannot be used for these types of applications. Therefore, it was necessary to research all suitable materials and analyze what difficulties may occur while manufacturing. Three of these materials were chosen regarding its behavior while manufacturing, chemical and physical properties, toxicity, and waste manipulation. After the research it was necessary to compare current knowledge from Asphericon s.r.o and the mother company Asphericon GmbH with machining similar or similarly behaving materials.

To perform the whole manufacturing process, it was necessary to propose all the steps from the cutting of raw material, through grinding, up to polishing with specific tool speeds, tool types and processing times were designed.

The quality of the polished surfaces was examined on specific measuring machines available in Asphericon s.r.o. The measurement procedures were defined for plano, spherical and aspherical surfaces. The measuring was performed according to ISO 10110 standards. Measuring requirements were fulfilled for all measured samples.

A proper number of samples for each process development were defined. From the manufactured samples, several of them were chosen for final verification - convex-concave aspherical lens with 110 mm mechanical diameter.

Eventually all the proposed processes were tested. The most suitable was selected for process verification. The process is refined to meet the required specification. The process reliability will be demonstrated as well. The process must be proven to be a repeatable achievement of the required parameters in a reasonable schedule.

2. Overview of materials used in infrared spectrum

The infrared specter is usually defined in the wavelength range from 0.75 µm to 1000 µm and is divided into five groups (Table 1). Materials working in a range of short, mid, and long infrared are important for this project.

Table 1 Infrared wavelength range divided into five subgroups.

Near – infrared	Short-wavelength infrared	Mid – wavelength infrared	Long-wavelength infrared	Far infrared
0,75–1,4 µm	1,4–3 µm	3–8 µm	8–15 µm	15–1000 µm

For the preliminary test seven materials applicable for the required range are listed in the table below. The materials are chosen based on their optical properties, but also toxicity, machinability, and price. A detailed literature review was done, because from the wide range of known materials working in given wavelength is most of them extremely difficult to manufacture.

From all the materials, those dissolvable by water are excluded because most of the liquids used in the manufacturing process are cooling agents and polishing slurries and are waterbased. A vast majority of the materials is prone to corrosion after finishing. Toxic materials were excluded as well.

Table 2 – Materials chosen for preliminary tests and its transmittances

Calcium fluoride (CaF2)	Germanium (Ge)	Chalcogenide Glass IG2	Chalcogenide Glass IG6	Silicon (Si)	Zinc sulfide (ZnS)	Zinc selenide (ZnSe)
180 nm – 8,0 µm	2,0 µm – 16,0 µm	1,0 µm – 11,0 µm	1,5 µm – 12,0 µm	1,2 µm – 8,0 µm	600 nm – 12 µm	600 nm – 16 µm

In the literature, research has been focused primarily on criteria that can limit the possible micro-roughness of the final surface. The hardness of the material is one of the issues. It is a well-known fact that the reduction of micro-roughness on soft materials is much more difficult than on harder ones. Another important parameter is the inner structure of the material. Amorphous materials are the easiest to polish into high surface quality, unfortunately, most of the IR materials are crystals. In the case of monocrystals, there is a problematic factor of the different removal rate in each of the crystal axis. On the other hand, the issue of polycrystals is different, removal rates on every single crystal which can lead to copping of the crystal structure into the surface. The last main parameter is the chemical reactivity with different polishing suspension, also under different pH values. The pH value is very important because the polishing process, and even more so on these materials, is extremely sensitive to the pH of the slurry.

The research of the materials resulted in choosing three materials fulfilling the requirements.

1.1. Chalcogenide glass IG2

For the project, chalcogenide glass IG2 from the company Vitron, was chosen. In comparison to other possible materials, this material is amorphous. In Asphericon was reached 4 nm rms by the SPDT on the aspherical surface. On chalcogenide glasses were also tested smoothening by the MRF. The reached micro-roughness was 0.48 nm rms, but only for wavelengths under 80 nm. IG2 glass is toxic, therefore during the process necessary precautions had to be taken.

1.2. Silicon (Si)

Silicon in the optical industry is used in the monocrystal form. The material has a suitable hardness and is chemically stable. Therefore, it can be polished by most of the standard polishing slurries, even with Cerium oxide-based slurry which is not possible to use for the rest of the materials. On the asphere again using standard polyurethane foil and cerium oxide-based slurry, a micro-roughness of 2.3 nm was reached without any optimization.

1.3. Zinc sulphide (ZnS)

Zinc sulphide has a transmission from the visible specter up to the wavelength 12 µm. This makes it a great choice for a wide range of applications. The polishing of ZnS is challenging due to the softness of the material and due to the chemical characteristics, which makes it impossible to polish using standard cerium oxide-based slurry. The ZnS is polycrystal, therefore MRF polishing was useless. The best method for polishing was to use full aperture tools. This method decreased the micro-roughness down to 1 nm rms but not measured in that wide frequency range.

3. Polishing process

1.4. Preparation

For the process several things had to be designed. For plano polishing a new sample holder was created. The new holder allowed polishing up to six samples at the same time. Samples were loosely placed into the holder without gluing. The holder also eliminates differences in the central thickness.

In the aspherical polishing, it was necessary to solve the precise dosing of the polishing slurry. For this purpose, a small peristaltic pump was mounted to the chamber of the CNC polishing machine. This pump precisely dosed polishing slurry into the process. With the pump it is possible to externally control the temperature of the slurry and prevent settling of the particles

1.5. Development

For infrared materials the optimization of polishing pad and slurry is essential. Most of the selected materials are extremely sensitive to a correct pad-slurry combination. Moreover, the slurry itself must be highly optimized, and not only in the way of the selection of basic components, grain size, temperature, and density but also in the way of controlling pH value, viscosity, and many other factors. The pad and slurry optimization work is mainly planned to be done on a crank arm polishing machine. The machine is very suitable for this kind of word because all parameters can be easily controlled.

In Asphericon good results were reached using its standard polishing process for aspherical surfaces also on infrared material. Micro-roughness was not good enough for this project but great as a starting point for final polishing. We will focus to develop pre-polishing based on this standard polishing process using the bonnet tool. Another promising way seems to be the use of standard polishing pitch in CNC. Both ways lead to the construction of a new polishing tool and of a polishing slurry dosing system which allows using special slurries and will be suitable for developed tools and kinematic.

1.5.1. Polishing process of Silicon (Si)

The aim was to find a suitable combination of polishing pad and polishing slurry. The problem with Si was its hardness. The hardness led to a long-lasting process. With a proper combination it was possible to obtain micro-roughness around 0,94 nm which already meets the requirements.

Figure 1 Aspherical lenses made of Silicon

	Target / goal	Result
Microroughness (rms)	1 nm / 0,5 nm	0,94 nm
Surface error ø50 mm (rms)	45 nm	164 nm

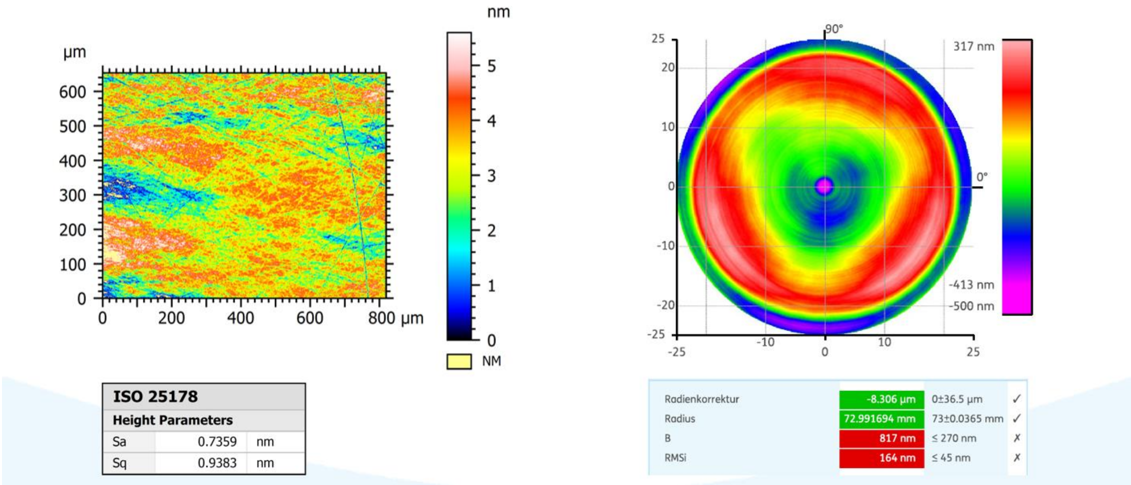

Figure 2 Micro-roughness and surface form deviation of Si aspheres

1.5.2. Polishing process of Zinc sulphide (ZnS)

The challenge with ZnS was its polycrystalline structure. An inappropriate combination of polishing pad – polishing slurry led to the formation of crystals. The goal value for micro-roughness was set to 1,5 nm rms and the obtained result got very close to it with 1,7 nm rms. Experience gained with the polycrystalline material is considered as one of the biggest successes of the project.

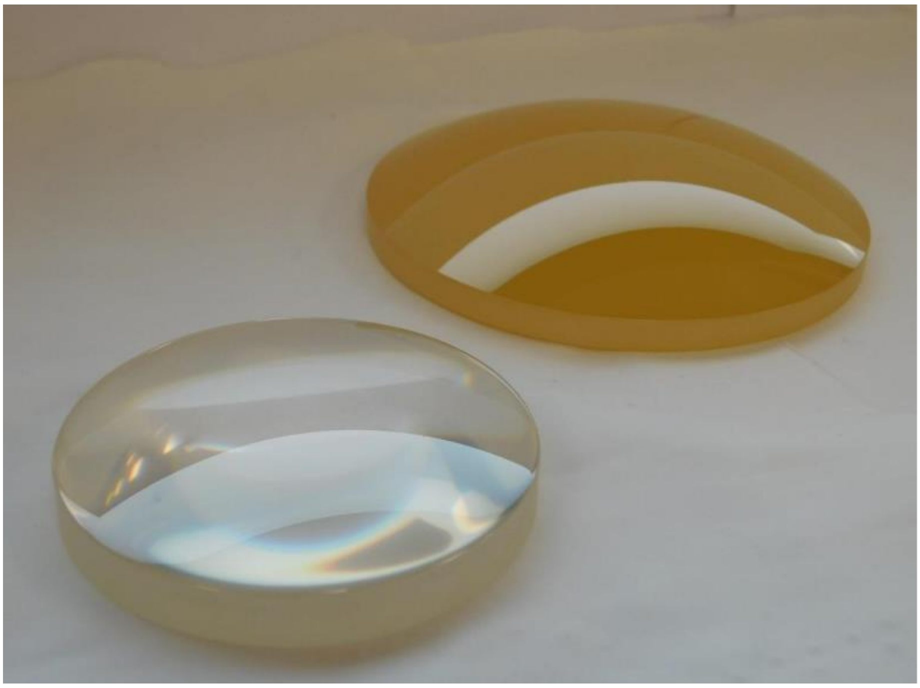

Figure 3 Aspherical lenses made of Zinc sulfide

	Target / goal	Result
Microroughness (rms)	1,5 nm / 1 nm	1,7 nm
Surface error ø50 mm (rms)	45 nm	56 nm

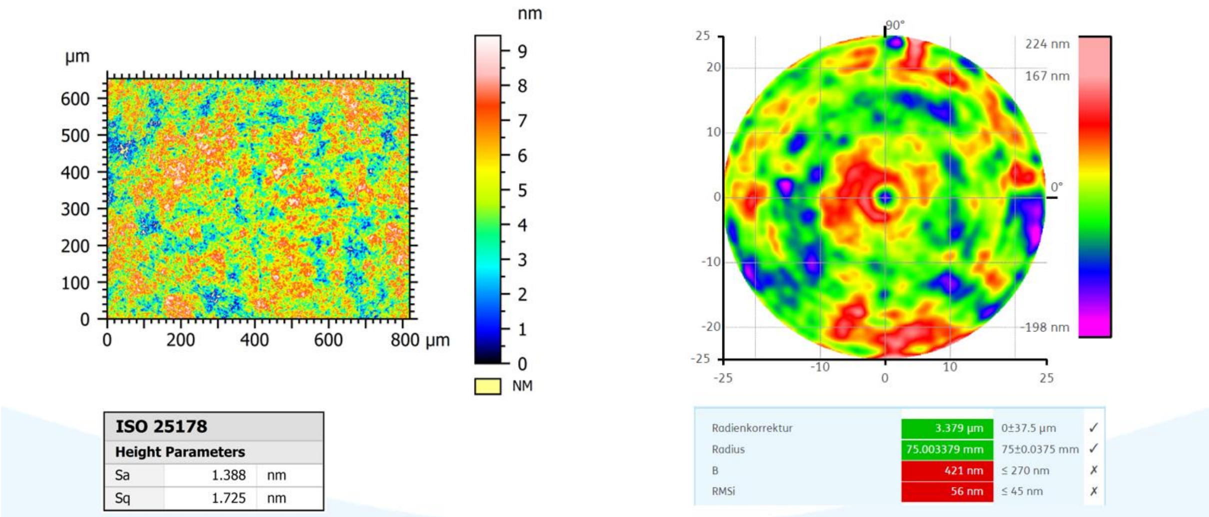

Figure 4 Micro-roughness and surface form deviation of ZnS aspheres

1.5.3. Polishing process of IG2

In the previous experiments on IG2, we had big issues in the pre-polishing process because the pollutants from IG2 are not only toxic but also dissolving optical pitch. For this reason, lubricant and oxidant were added to the slurry to suppress this effect. IG2 glass is well machinable so even though the micro-roughness after pre polishing was 7 nm, the first final polishing led to 1,126 nm. The goal was still not reached, so it was decided to change the slurry. This change led to improving the micro-roughness to 0,93 nm on a convex surface and 0,99 nm on a concave surface.

Figure 5 Aspherical lenses made of IG2

	Target / goal	Result
Microroughness (rms)	1 nm / 0,5 nm	0,93 nm
Surface error ø50 mm (rms)	45 nm	31 nm

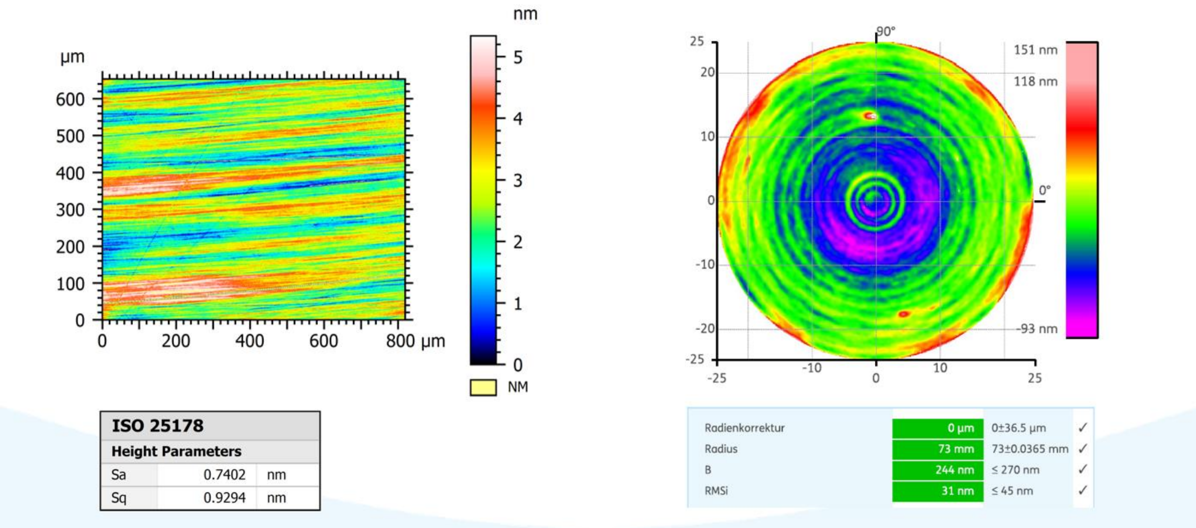

Figure 6 Micro-roughness and surface form deviation of IG2 aspheres

1.6. Surface form correction

During the process multiple technical issues occurred. These issues made impossible to use correction polishing for the final lenses. The problem occurred after polishing 60mm aspheres, therefore at least these elements may be tested and presented.

The problem with Si was caused by its crystalline structure. During the machining the structure led to formation of trefoil. This error was visible after final polishing. The higher removal suppresses the difference between removal around the crystal structure but led to increasing microroughness. The other possibility could be to use highly alkaline slurry, but if the slurry is used with IG2 could lead to production of highly toxic AsH_3.

On ZnS form correction works very well and the irregularity value was only 56 nm rms. It is visible on the figure that all the rotationally symmetric structures were properly corrected. Mainly the asymmetry without any pater was left on the surface. It is most probably caused by the inhomogeneity of the material.

Because the IG2 is an amorphous material, and its characteristics are closest to standard glass from all tested materials the form correction polishing has the best results. Irregularity on the asphere of diameter 60 mm was reduced to 31 nm rms almost without any asymmetry and with zero radius deviation.

4. Conclusion

Manufacturing processes for all selected materials (Si, ZnS, IG2) were successfully designed in the project.

Polishing of the asphere made of silicon monocrystal showed us the critical issue which is the orientation of the crystalline structure having influence on the removal rate and leading to trefoil form deviation. The problem is also the low abrasiveness of the material leading to long production times.

Zinc sulfide with its specific polycrystalline structure brings us a new and non-intuitive experience of balancing the proper grain size of the polishing slurry with process parameters to get the best possible results.

IG2 as soft, fragile, and toxic material gave us a good view into the problem of health risks, toxic waste handling but also into the area of high advance adjustment of polishing slurry properties using lubricants and oxidants

The general benefit of this selection is that it was necessary to do a very proper plan of all experiments and of the ancillary works (machine cleaning) to be able to stay in a reasonable time and money frame and have constantly good quality.

The last-mentioned advantage is on the other hand also a disadvantage. Managing so many different production processes, what's more, even with toxic material was extremely difficult and very time-consuming. Not only the production time scheme but also resources, mainly slurry use, was necessary to plan in detail. Without that, the slurry consumption would be extremely high and therefore also expenses. Another issue was that the production had to be stopped often for cleaning the machines. Proper cleaning was important between slurry changes to ensure surface quality, but it must be cleaned even more often when IG2 was produced due to toxic pollutants. The cleaning of course must be done under health and safety restrictions. These limitations caused the polishing processes not to be a hundred percent optimized. One of the experiences for future projects is that if the goal is to develop a manufacturing process optimized to its limit, then it is necessary to choose fewer materials (maybe only one) or at least from one group. If the goal is the technological progress and gaining as much experience as possible then the choice of a wide range of materials, as we did, is the right one.

The greatest space for improvement of the process is in the polishing of the silicon. It will be necessary to suppress the occurrence of the trefoil on the surface. Currently three ways are open for process improvement. First is 3D correction polishing which allows to polish out also asymmetry on the surface. It is done by using the workpiece spindle in axis mode. Thanks to this, the orientation of the lens is known, and removal can be controlled within one revolution. The issue of this process is that the removal is given only by tool rotation and therefore is very low.

The polishing process of ZnS was highly optimized. But it can still be improved mainly by adjusting the slurry properties. Ideal slurry grain size could be found. The slurry should be as fine as possible but not that fine that polycrystalline structure occurs on the surface. Slurry concentration would be optimized too. From our experiments, it seems that the high concentration works better. But the not exact value was found. Some room could be also in pad optimization. We found out that the filling of the polyurethane is undesirable, but the diamond filling was not tested. Different porosity could have a positive effect too.

At first, it is necessary to improve all the procedural matters related to the toxicity of the material in the case of IG2. In a better-prepared production line, the polishing process can be easily optimized.

Important is also to be focused only on a particular material because the combination with other material makes improvements very difficult. The process itself can be improved by slurry a pad. As results showed two slurries with similar grain sizes but different viscosity produced surfaces with significantly different microroughness. This effect must be further examined. In the case of the polyurethane pad is potential for the removal rate increase. Using polyurethane filled with zirconium oxide the removal rate was increased approximately three times, but the surface quality was not sufficient. But if we will understand the causes optimization should be possible.