Prototyping platform for laser-based sensor technologies: Inspection of conversion coatings on alumina substrates

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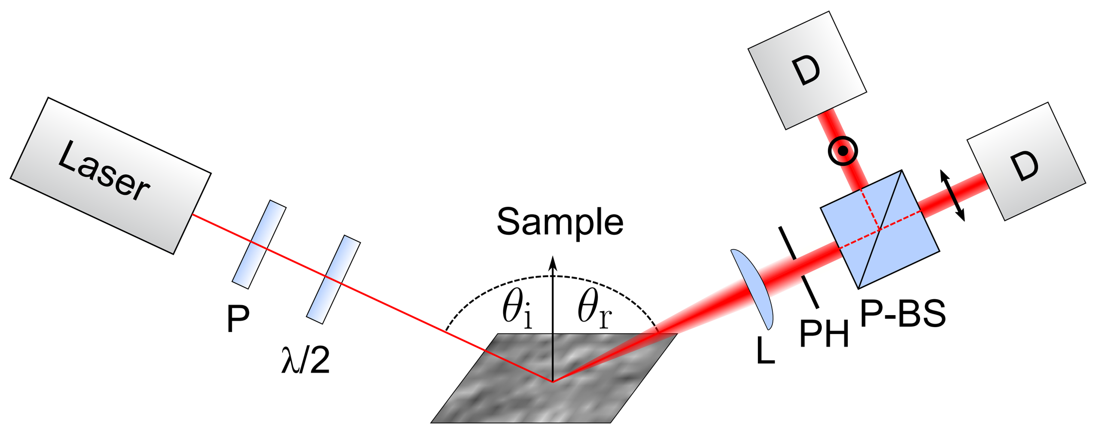
Content

Transferring laser-based sensors into industrial applications, for instance for the contact- and destruction-free inline quality control of alumina alloys, is very challenging due to laser-safety requirements and the complex implementation in individual technological infrastructures. In order to open laser-based sensor technology even for small to medium size enterprises, we introduce a prototyping platform for laser-based sensor technologies that enables the fast, error-free, flexible and low cost transformation into industry. As an example, the transformation of the laser-based sensor concept using coherent light scattering at technical insulating films is shown[1,2]. The transformation of this type of sensor is particularly demanding due to the requirement of probing transparent conversion coatings, with a thickness of less than 70 nm, a thickness where commonly applied electronic techniques fail. The conversion films are produced on the top of cold-rolled, unpolished alumina in a way that coherently scattered laser light can be regarded as superposition from diffuse scattering processes at the surfaces/interfaces, inclusions and/or layer imperfections. Analysis is realized by extending the principle approach of reflectometry by considering the role of diffuse and specular scattering together with the concepts of light interferometry. The functionality of the transformed sensor is validated using different conversion coating thicknesses on AA3003 alumina substrates.

Sensor Concept



- Affordable light source (a laser pointer is sufficient)
- Adjustable intensity and polarization
- Detection of the specular spot
- Parameter of interest is the relative reflectance ΔR
- Strong correlation between ΔR and layer thickness d

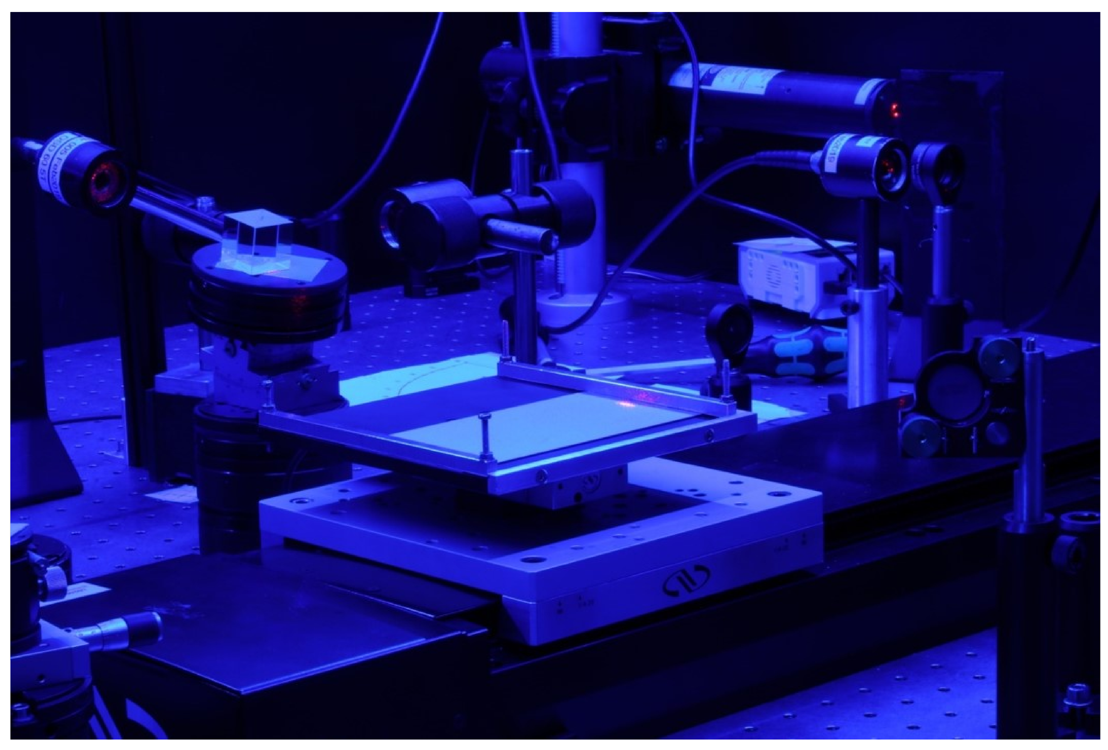
$$\Delta R(\theta_\mathrm{i}, \theta_\mathrm{r}, d) = \frac{R_\mathrm{s}(\theta_\mathrm{i}, \theta_\mathrm{r}, d)}{R_\mathrm{p}(\theta_\mathrm{i}, \theta_\mathrm{r}, d)}$$

While dents, scratches and bends in the sample geometry do not have an influence on the shown factor, it is highly sensitive for thin layers in the range of 20 nm - 70 nm. A table displaying the sample preparation is shown below. Main influence on the signal arises from interference.

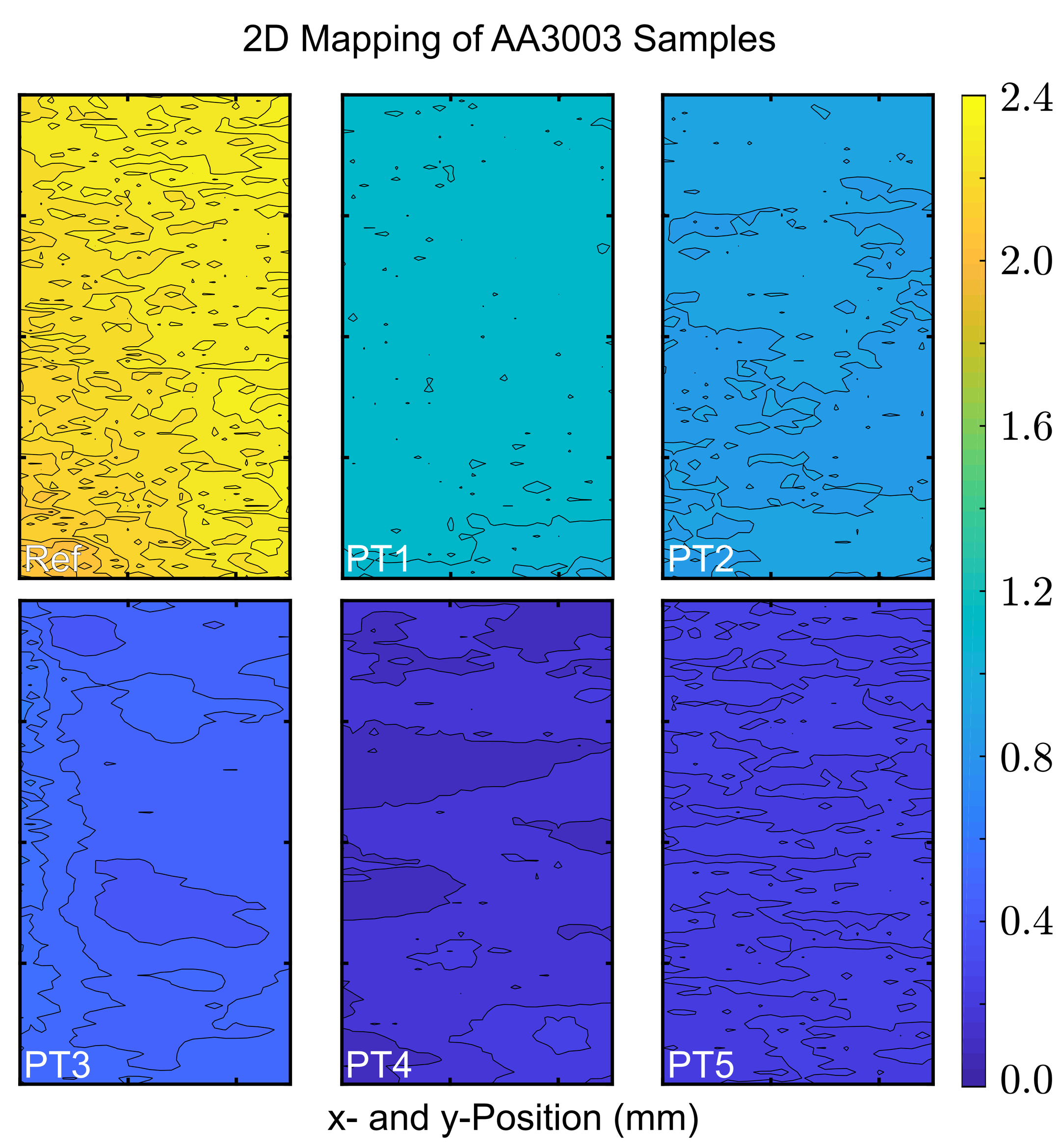
- Samples were coated with SurTec650™ (Cr^{3+} and Zr^{4+})[3]
- Substrate from a single process to minimize deviations
- Reference (Ref) went through all steps except coating
- Five different coating qualities (PT1-5)

sample	dip-duration (s)	temperature (°C)	mass of layer (g/m²)
PT1	60	30	0.11
PT2	60	40	0.20
PT3	180	30	0.36
PT4	180	40	0.43
PT5	300	30	0.47

Laboratory Setup & Results

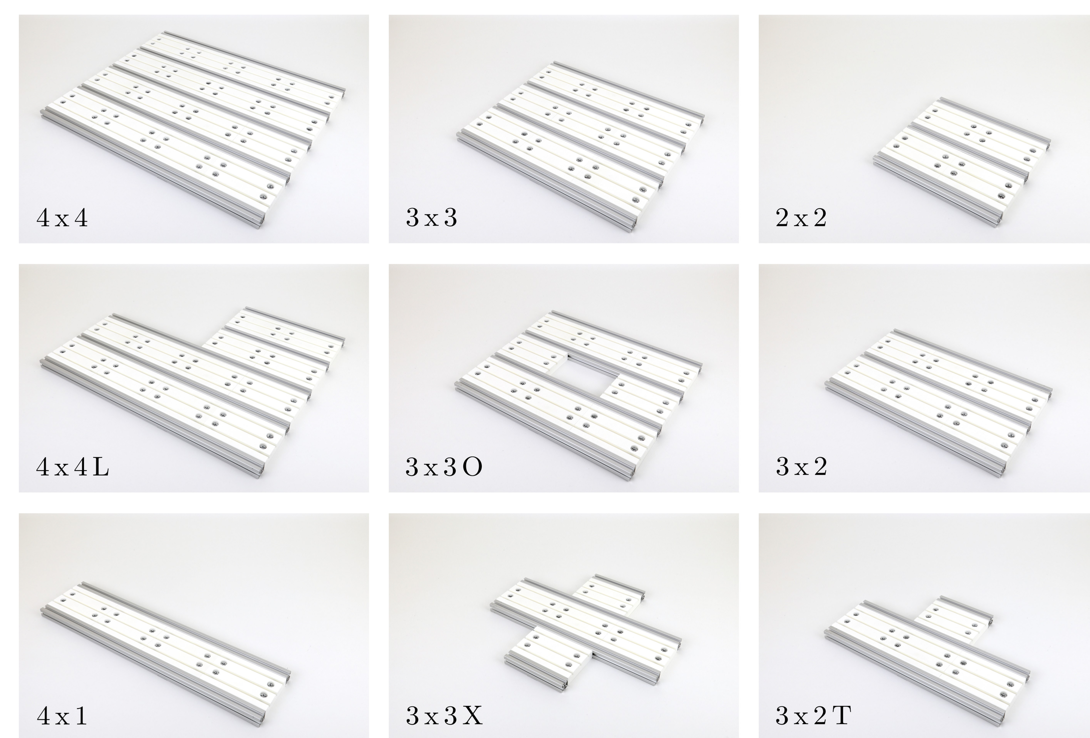


The photograph above shows the laboratory setup used for the 2D mapping shown in the figure below. Yellow represents no layer (Ref) and the dark blue a conversion layer (PT5) of ~70 nm thickness. A clear difference between each sample is prominent with a small deviation in shade.

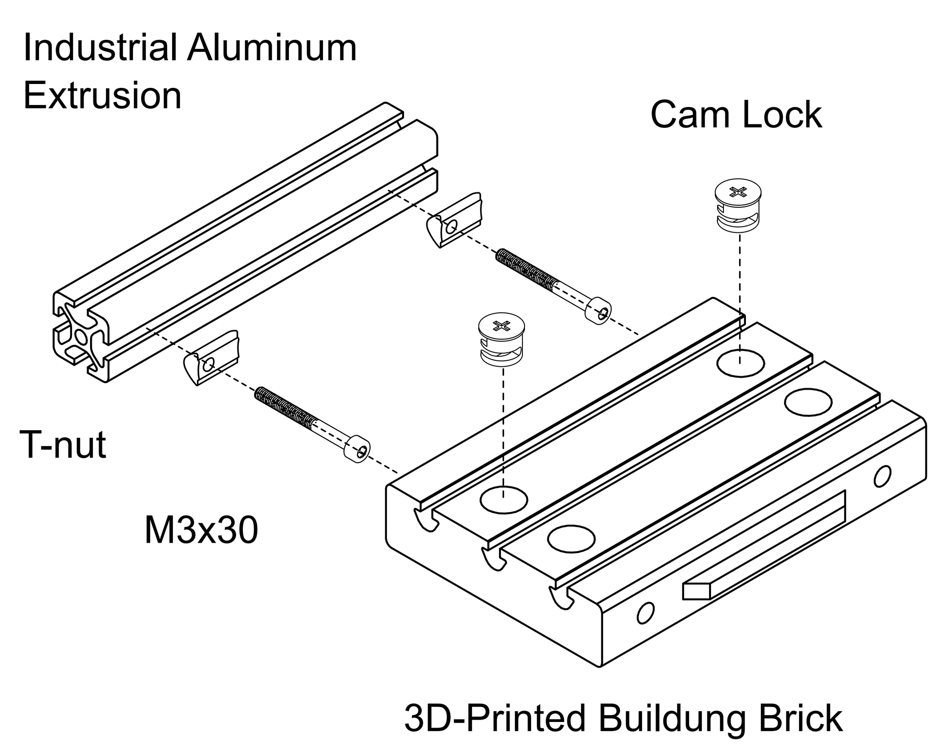


- Laboratory Setup
- Optical power: < 1.0 mW
- Area: 25 mm x 80 mm
- Resolution: 1 mm²

- The platform is much cheaper than comparable solutions due to its use of 3D-printing technology in combination with industrial aluminum extrusions.
- The platform is compatible with established construction and state-of-the-art building kit systems.
- The platform allows for an easy and fast adjustment of optical components `on the fly´ by combining individual advantages of 1D optical benches and 2D optical breadboards.

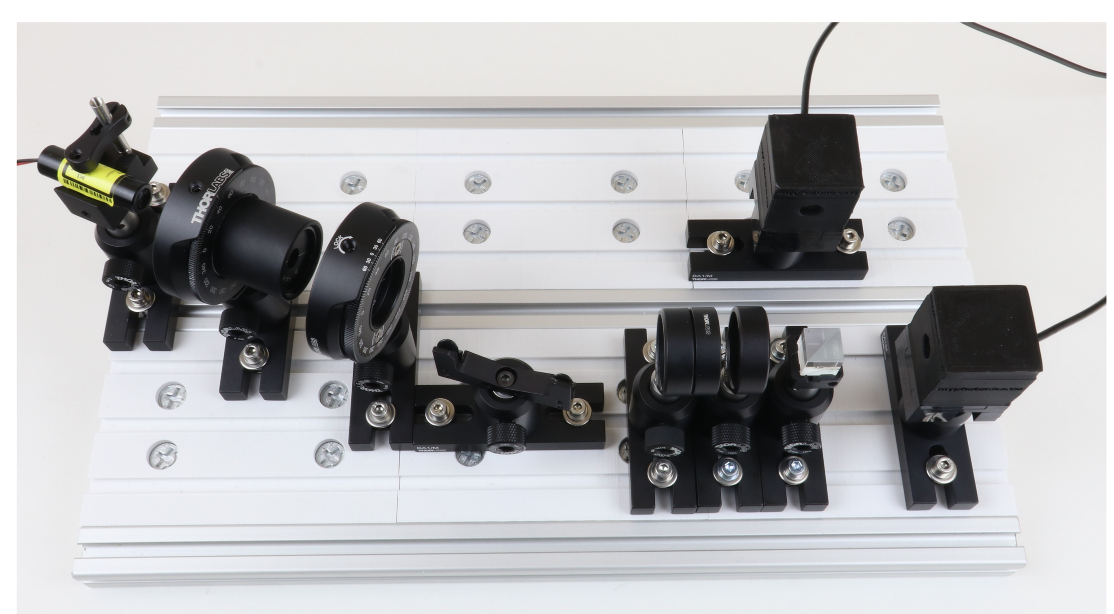


Prototyping Platform

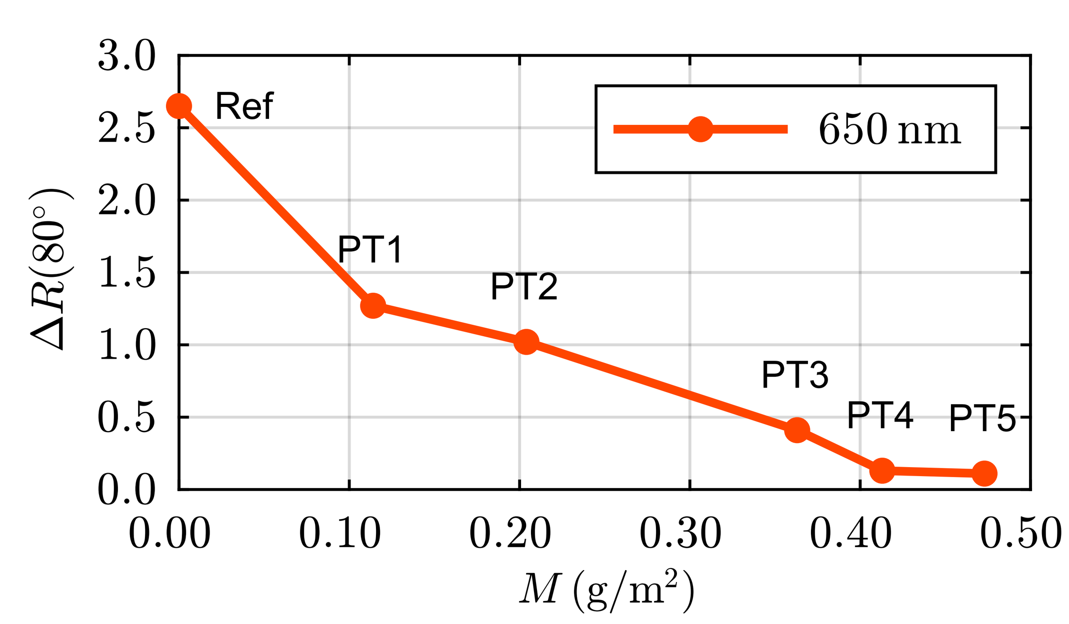


The prototyping platform enables the user to assemble optical breadboards using 3D-printed building bricks with incorporated honeycomb structure, so-called 'breadboard bricks'. With this do-it-yourself approach, it is possible to make changes to the breadboard, such as making an opening, changing its shape or increasing the mounting surface whenever needed.

Prototype Validation



- The sensor concept was transformed into a fixed prototype
- Each sample was meassured again (650 nm, 80° AOI)
- A successful validation has been achieved



Conclusion

The presented prototyping platform was usccessfully used to transfer the sensor concept into a working prototype. The functionality of the transformed sensor was validated using different conversion coating thicknesses on AA3003 alumina substrates in the range of 20 nm - 70 nm. A fixed geometry in combination with an affordable laser source (650 nm diode) was chosen. The resulting prototype is portable, agile and easily extendable in the context of changing optical componentes. An extension of this setup might be applicable to cover the entire surface area of the processed sheets.

Citations

1 Rischmueller et al., Inspection of Trivalent Chromium Conversion Coatings Using Laser Light: The Unexpected Role of Interference on Cold-Rolled Aluminium. *Sensors* **2020**, 20, 2164.

2 Toschke et al., A modular optical honeycomb breadboard realized with 3D-printable building bricks and industrial aluminum extrusions, *HardwareX* **2021**, Volume 9, e00182.

3 Data sheet SurTec 650™

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