Freeform optics enabling high dynamic scanning for line structuring of large substrates

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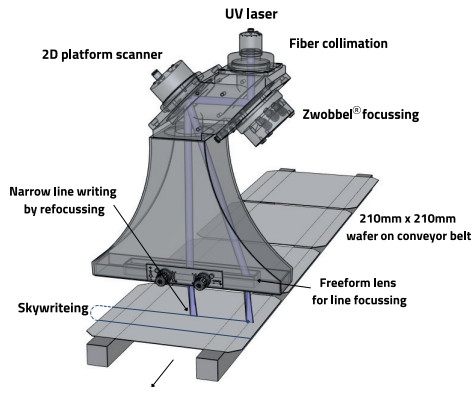
ABSTRACT

= Ultrashort pulsed lasers with 2 µm wavelength are ideal for material processing of plastics, such as welding, marking, and cutting
= Scanning systems are essential for processing large substrates
= Novel approach for line structuring using Zwobbel technology with freeform optics, developed in UKPino project, is presented
= Approach aims for faster processing on larger substrates, particularly for roll-2-roll processes
= Scanning across cylindrical lens generates strong image field curvature, which can be compensated by extending lens geometry to freeform lens
= Processing field can be further extended by combining freeform lens with a deformable mirror that shifts focal position
= Zwobbel technology, a piezo actuator-based deformable mirror with fast step responses (<2 milliseconds) and wafer scanning capability of up to 333 lines per second, has been selected
= System generates sufficient lines on M12 substrates

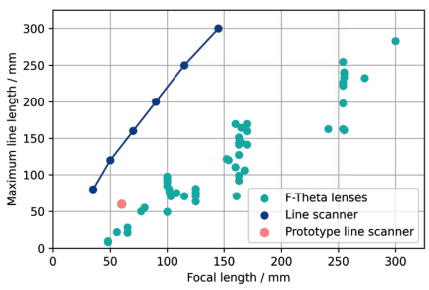
CONCEPT

= Roll-2-roll applications need the highest scan speeds for line structuring
= Precise polygonscanner with focus correction shall be used for 2D scanning
= Freeform lens design is employed to generate narrow lines
= Roll is structured during movement
= Scanner needs fast speeds perpendicular to roll movement, and some roll speed compensation is needed



OPTICAL DESIGN

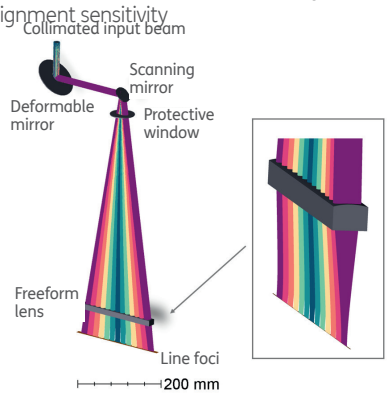
Limitations of state of the art optics



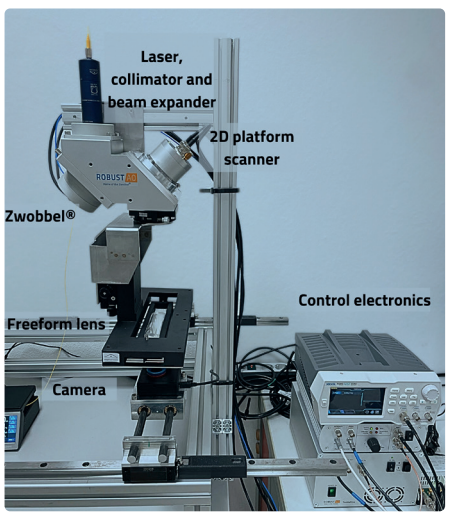
= Conventional line writing with f-theta lenses requires short focal length for narrow lines
= For given focal length, there is upper limit to field size and thus the maximum line length, regardless of the f-theta lens manufacturer
= Extending line length without increasing line width requires novel approach
= New line scanner, with focal length and field size highlighted in figure above, is presented
= Scanner doubles line length compared to conventional f-theta lenses of same focal length

System layout

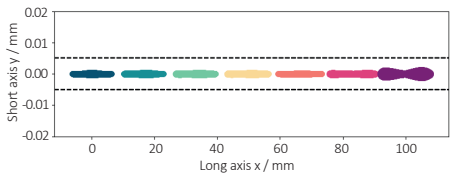
= Collimated input beam deflected by deformable mirror at a 90° angle to hit scanning mirror
= Beam passes through freeform, forming line
= focus
Depending on mirror angle, light passes through
= different segments of freeform lens
Freeform lens and Zwobbel amplitude are finely tuned for optimal manufacturability and low alignment sensitivity



Experimental setup

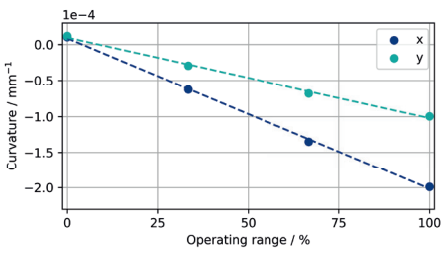


Spot diagrams demonstrate excellent focusing capabilities across whole field:



Parameterization of deformable mirror Zwobbel

= Surface measurements of Zwobbel's mirror at different deformation stages are analyzed
= Radii of curvature along long and short axes are used as basis for parameterization in optical design software



DEFORMABLE MIRROR USABILITY

Objective

= Evaluate deformable mirror technology in 2 µm roll-2-roll applications, focusing on high scan speeds

Technology

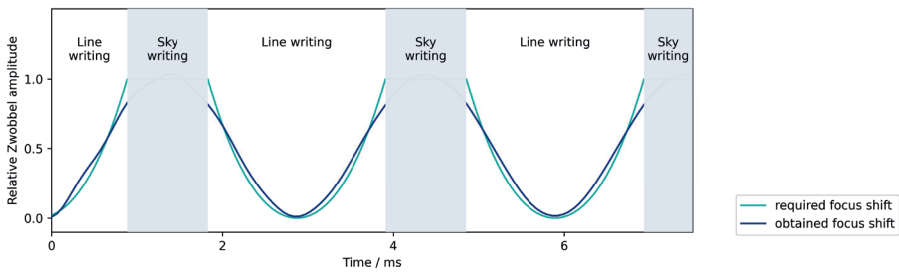
= **Mirror Type:** Zwobbel deformable mirror, designed for fast focusing and space-saving.
= **Actuation:** Piezoelectric actuators enable high speeds with excellent dynamics.
= **Hysteresis:** An integrated absolute sensor ensures reproducible positioning

Mirror Design

= 90° deflection with bi-conical deformation to avoid astigmatic aberrations.
= **Coating:** Over 99.9% reflectivity between 1µm and 2µm with minimal polarization difference

Measurement Methods

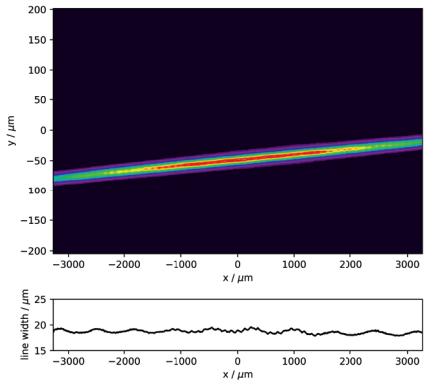
= **M² Measurement:** 1064nm wavelength, beam diameter up to 15 mm for precise quality assessment
= **Dynamic Mirror Deflection**: Capacitive sensor with 5kHz sampling frequency



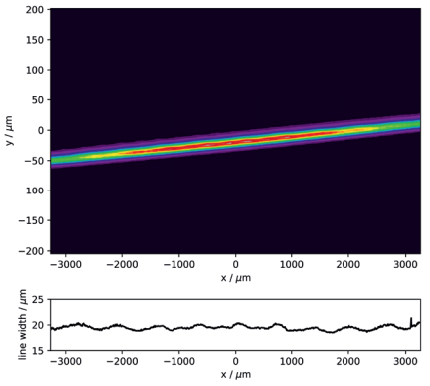
PROOF OF CONCEPT DEMONSTRATION

= Focal length freeform lens: 60 mm
= Wavelength: 1064 nm
= Input beam diameter: 10 mm
= Scan field: 60 mm (limited by scanner)
= Diffraction limited line width: 16 µm
= Achieved line width: 18 – 21 µm

Central field position



Maximum field position



SUMMARY AND CONCLUSION

= Novel line scanner utilizing freeform optics and Zwobbel technology has been developed to overcome limitations of conventional f-theta lenses, significantly extending line length without increasing line width
= Integration of deformable mirror and freeform lens optimizes beam path, allowing for precise line focusing and compensation of image field curvature
= Surface measurements of Zwobbel's mirror provide critical data for optical design, enhancing alignment and manufacturability of system
= Ultrashort pulsed lasers at a 2 µm wavelength, combined with this advanced scanning system, offer powerful solution for high-speed processing of large plastic substrates
= Collaboration within UKPino project has demonstrated potential of this technology for roll-2-roll processes, ensuring faster, more efficient material processing
= With step response times < 2 ms and scanning capability of 333 lines per sec, Zwobbel technology enables precise and efficient line generation on M12 substrates, making it ideal for large-scale applications

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