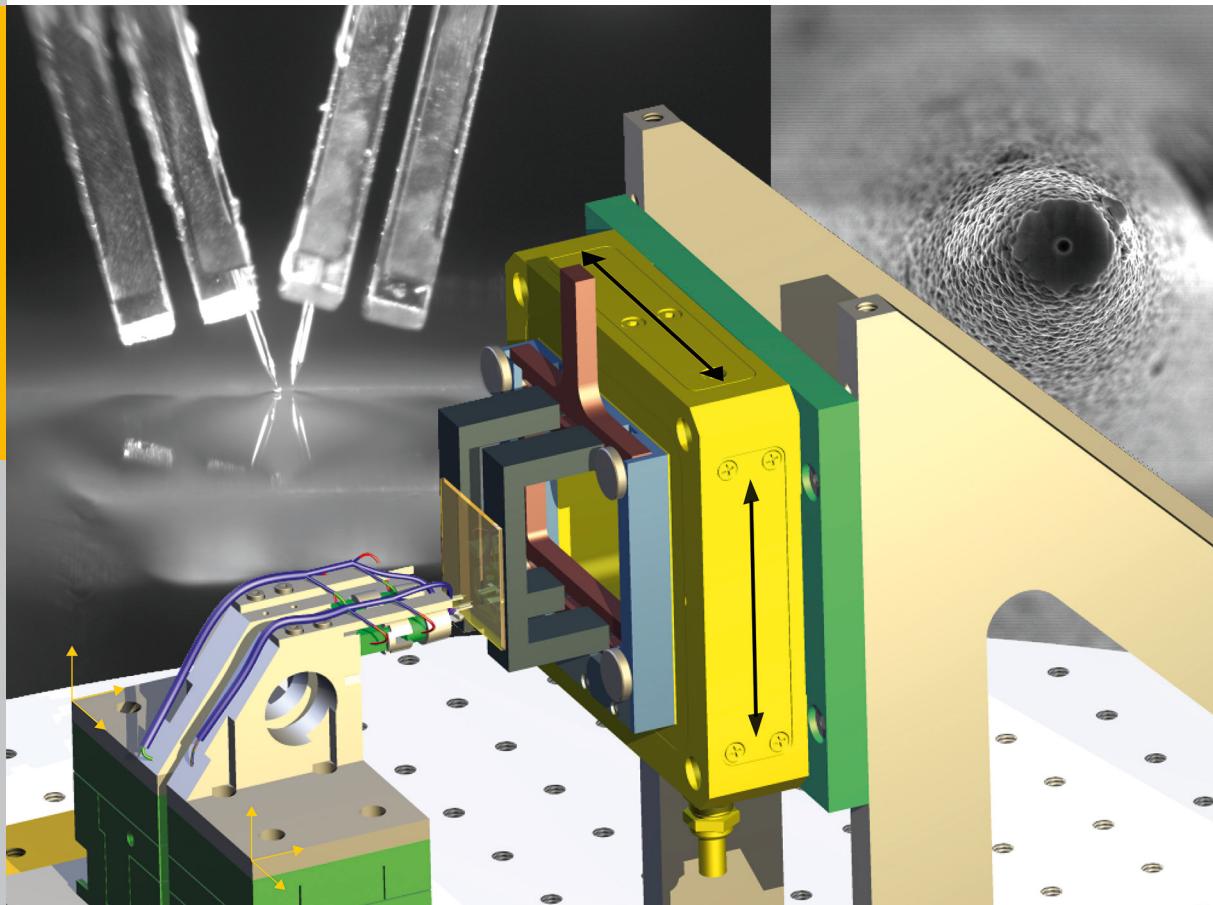


Investigation of light propagation in thin-film silicon solar cells by dual-probe scanning near-field optical microscopy

Stephan Lehnen

Member of the Helmholtz Association



Energie & Umwelt /
Energy & Environment
Band / Volume 270
ISBN 978-3-95806-066-1

 **JÜLICH**
FORSCHUNGSZENTRUM

Forschungszentrum Jülich GmbH
Institute of Energy and Climate Research
IEK-5 Photovoltaics

Investigation of light propagation in thin-film silicon solar cells by dual-probe scanning near-field optical microscopy

Stephan Lehnen

Schriften des Forschungszentrums Jülich
Reihe Energie & Umwelt / Energy & Environment

Band / Volume 270

ISSN 1866-1793

ISBN 978-3-95806-066-1

Contents

1	Introduction	7
2	Fundamentals	11
2.1	Diffraction	11
2.2	Diffraction Limited Resolution	12
2.2.1	Abbe Limit	13
2.3	Failure of the Kirchoff Theorem / Diffraction at Subwavelength Size Apertures	14
2.4	Beyond the Diffraction Limit	15
2.5	Light Trapping	19
2.5.1	Yablonovitch Limit	20
2.6	Shear-Force	25
2.7	Device-Structure of a Silicon Thin-Film Solar Cell in n-i-p Configuration .	26
3	System Setup	29
3.1	General Setup & Design Criteria for a Dual-Probe SNOM	29
3.2	Motorised Coarse Alignment	31
3.3	Piezo Fine Alignment	31
3.4	Shear-Force Distance Control	32
3.5	Cameras & Lighting	35
3.6	Vibration Isolation	36
3.7	Surface Markers	37
3.8	Laser & Optical Setup	38
3.9	Detector & Lock-In Technique	38
3.10	Estimate of the Maximal Distance in between the Probes	39
4	Optical Probes for Near-Field Microscopy	43
4.1	Apertureless Probes	43
4.2	Aperture Probes	43
4.2.1	Probe Etching	45
4.2.2	Probe Pulling	45

4.2.3	Coating	46
4.2.4	Aperture Adjustment	46
4.3	Probe Preparation	48
4.4	Probe Characterisation	51
5	Modes of Operation	55
5.1	Basic Modes of Operation	55
5.1.1	Collection Mode in Transmission Geometry	55
5.1.2	Collection Mode in Reflection Geometry	56
5.2	Dual-Probe Mode	57
5.2.1	Alignment of the Probes	58
5.2.2	Interaction between the Probes	59
5.3	Height-Scan Mode	60
6	Light Paths and Photon Loss Mechanisms in Dual Probe Measurements	63
6.1	Absorption in the Sample Material	64
6.2	Distribution inside the Layer	65
6.3	Reflection Losses	67
6.3.1	Theoretical Background	67
6.3.2	Intensity Decay due to Reflection Losses	70
6.4	Light Guidance in the TCO Layer	72
6.5	Direct Light Transfer between Illumination and Detection Probe	72
7	Measurement of the Light Propagation in thin films	75
7.1	Basic Dual-Probe Mode	75
7.1.1	Analysis by Line Scans	75
7.1.2	Analysis by Circular Averaging	77
7.2	Coupling Efficiency Eliminated Scan Mode	78
7.2.1	Wavelength & Texture Dependence of the Intensity Decay	80
7.3	Fact or Artefact?	82
7.3.1	De-convolution of the probe's shape from topography measurements	85
8	Simulations	87
8.1	Ray-Tracing Approach	87
8.1.1	Ray-tracing for Realistic Angular Distribution	89
8.1.2	Limitations of Ray-Tracing	92
8.2	FDTD Simulations	94
8.2.1	Limitations of the Simulation	100

8.2.2	Angular Distribution of the SNOM-Probe Emission/Sensitivity . . .	101
9	Summary & Outlook	105
9.1	Summary	105
9.2	Outlook	106
Zusammenfassung		109
References		117
Acknowledgments		119

**Energie & Umwelt/
Energy & Environment
Band / Volume 270
ISBN 978-3-95806-066-1**

