

Übertragungssysteme mit Singlemode-Fasern für 405 nm Laserlicht und deren Degradation

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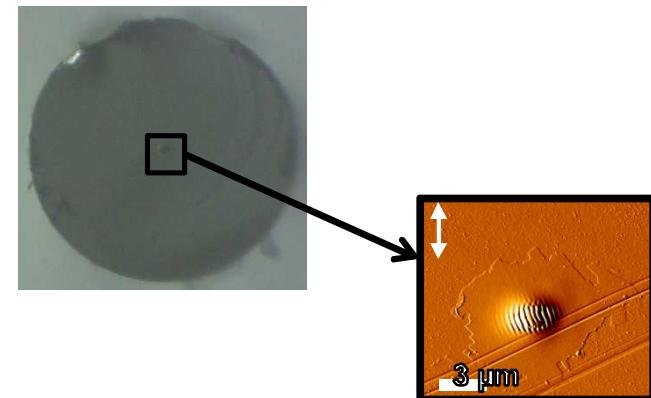
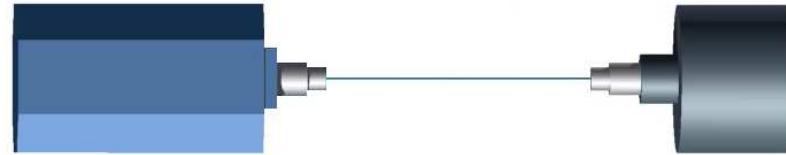
TransMIT GmbH, ZeFiL, Saarstr. 23, 61169 Friedberg

**5. Aalener Photoniktag
06. Dezember 2013**



Überblick

- Einleitung / Rückblick
- Verluste in faseroptischen Systemen
- Schädigung auf der Eingangsseite und deren Unterdrückung
- Schädigungsmodelle
- Schädigung auf der Ausgangsseite
- Zusammenfassung

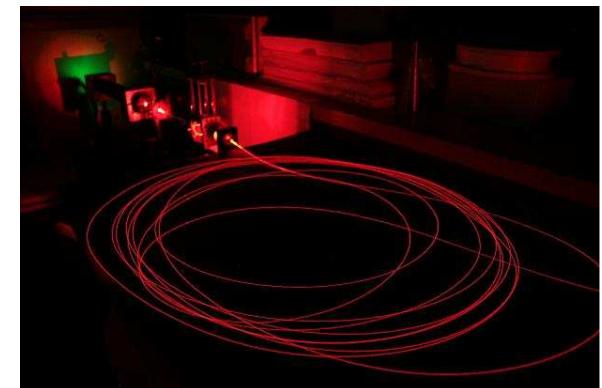


Oktober 1998 in Aalen:
**Grenzen und Möglichkeiten der Transmission
von UV-Licht durch Spezial-Lichtwellenleiter**

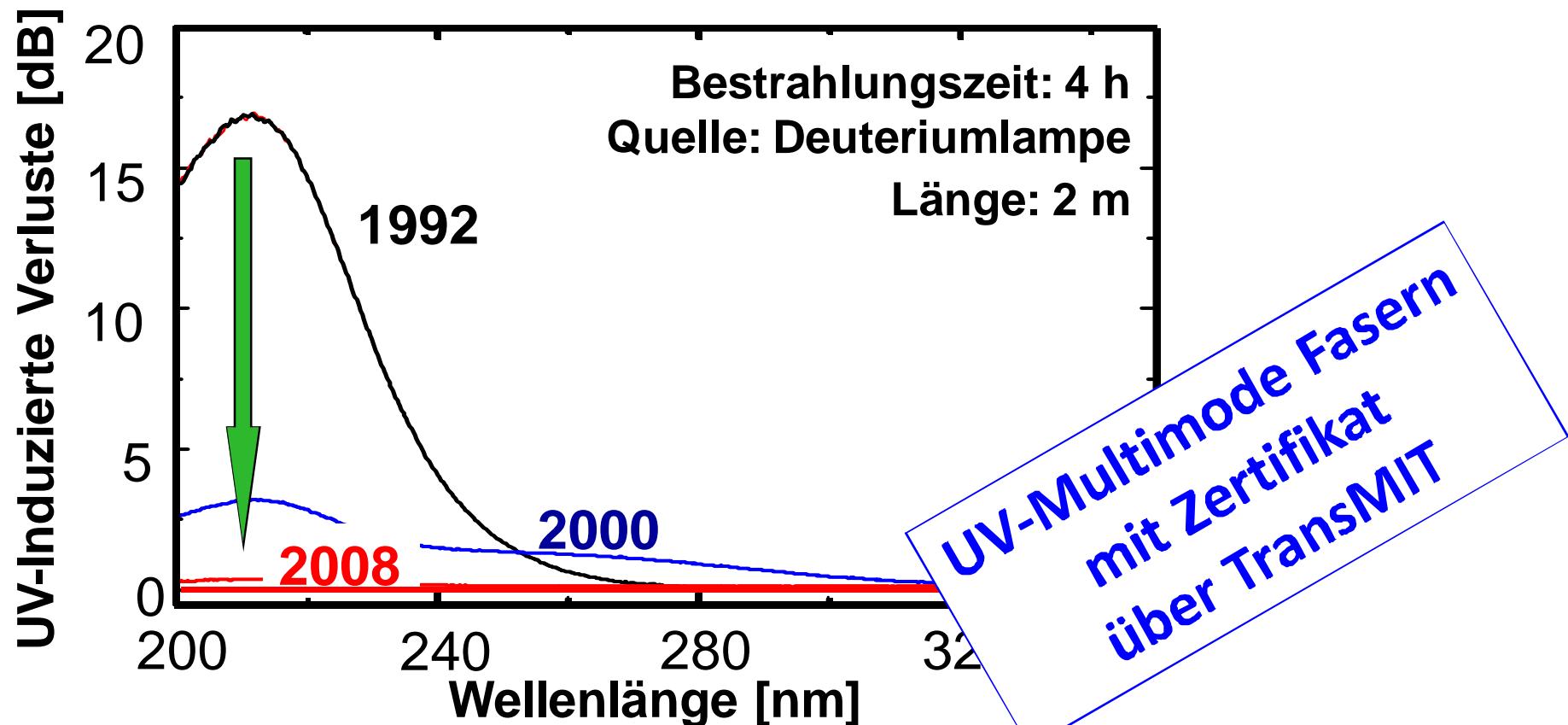
Zur Lichtübertragung im UV-Bereich, speziell unterhalb von 250 nm, kommen nur Lichtwellenleiter mit einem undotierten, OH-haltigen Quarzglaskern in Frage.

Es existieren verschiedene physikalische Grenzen für faseroptische Anwendungen in diesem Bereich, die von den UV-Quellen abhängen.

In den letzten Jahren konnten neue UV-stabile Fasern entwickelt werden, mit drastisch reduzierter Zusatzdämpfung.
Der aktuelle Stand ... wird vorgestellt.



- 1. Lösung: wasserstoff-beladene Fasern
- 2. Lösung: Herstellmodifikationen



„Neue“ UV-Applikationen

UV-Quellen

UV-Faser

UV-Faser

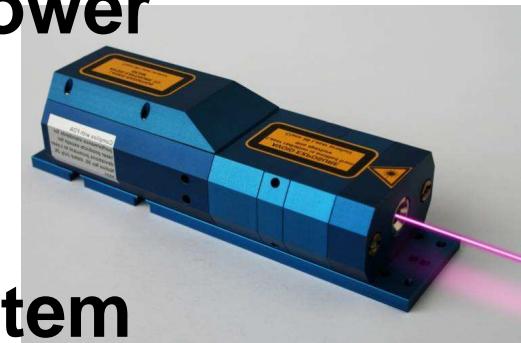
Detektoren

Applikationen:
extrinsische Effekte

Spektrale TLC-Methode mit Diodenzeilen
DUV-Tauchsonden
Flüssigkeitsanalysen mit UV-Flüssigkeitslichtwellenleiter
Flüssigkeitslichtwellenleiter mit seitlicher Beleuchtung
Gasanalysen mit UV-Hohlwellenleiter
!! Prozesskontrolle (“Leuchtturmprobe”) !!
Laserskalpel
Laser-induzierte Fluoreszenz (LiF)
LiF-Kapillarelektrophorese mit PMT

Motivation

- Compact SM lasers in the NUV and VIS region, with continuously increasing cw power

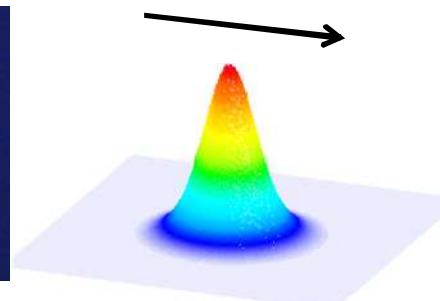
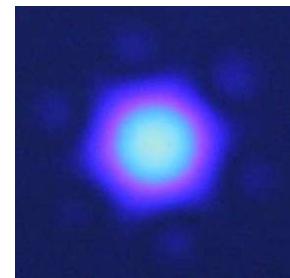
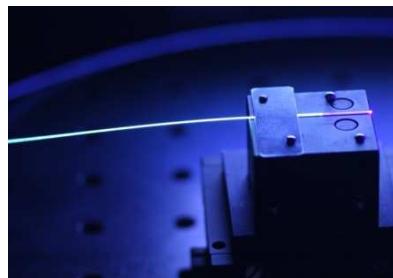


- Properties of SM fiber-coupled system

Flexibility

Beam quality ($M^2 < 1.1$)

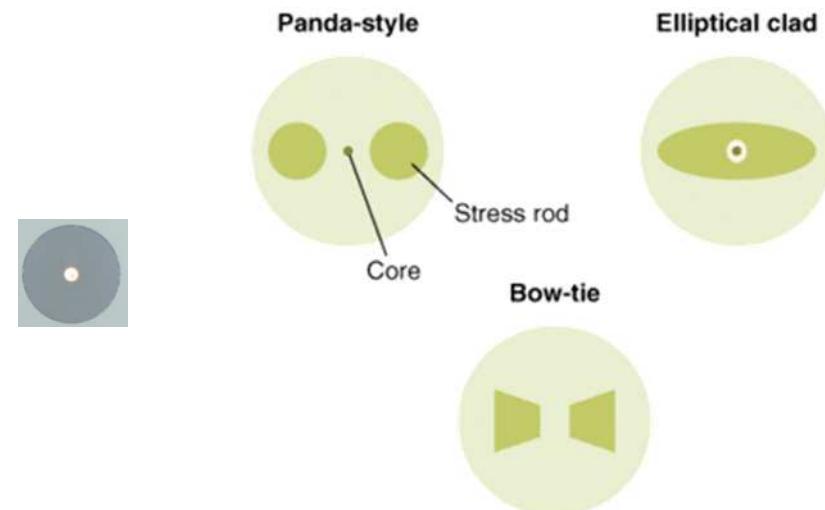
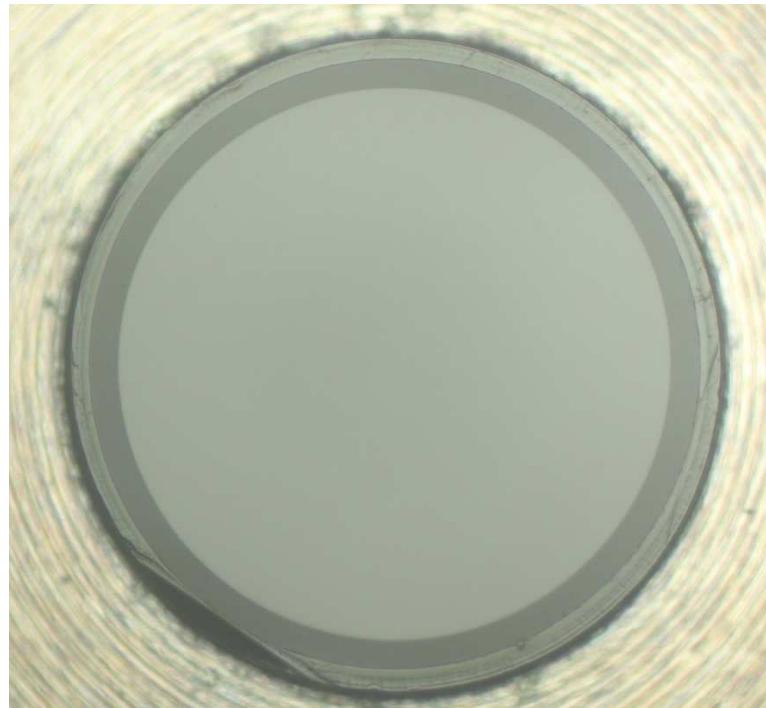
Polarisation



Target: Degradation

- **End-user (multiple)**
“Degradation of single-mode fiber delivery systems using **405 nm** diode lasers.”
- **Laser module manufacturer about fiber-coupling (Coherent)**
“... at wavelengths less than about **450 nm**, output power can drop about 100 times more rapidly than at longer wavelengths. .. somewhat surprising finding, since intensity about 500 to 1000 times less than optical damage threshold.”

SM-fiber vs. MM-fiber



<http://www.nufern.com/>

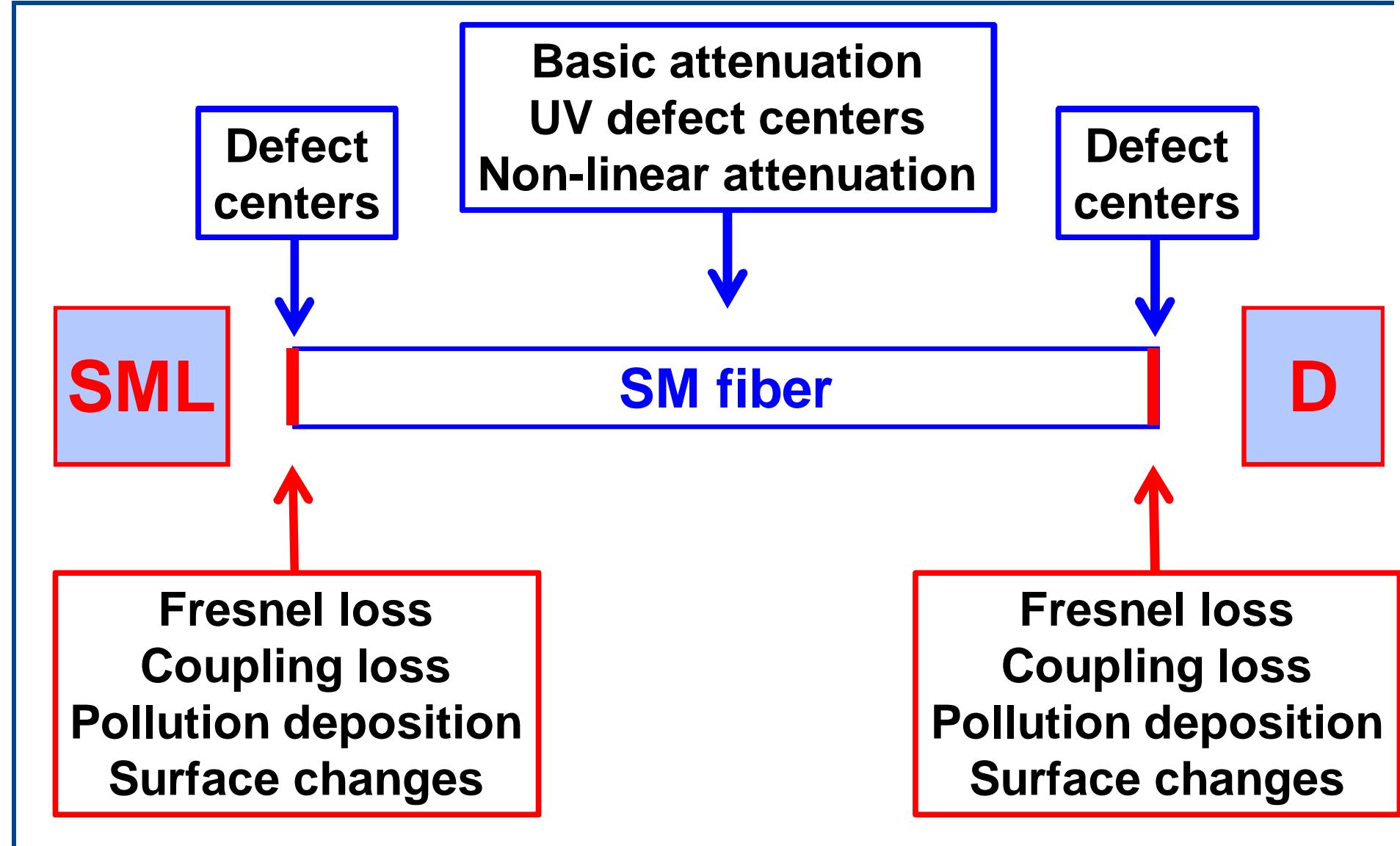
Significantly smaller core diameter

2 - 3 μm (SM & PM) at $\lambda = 375\text{-}425 \text{ nm}$

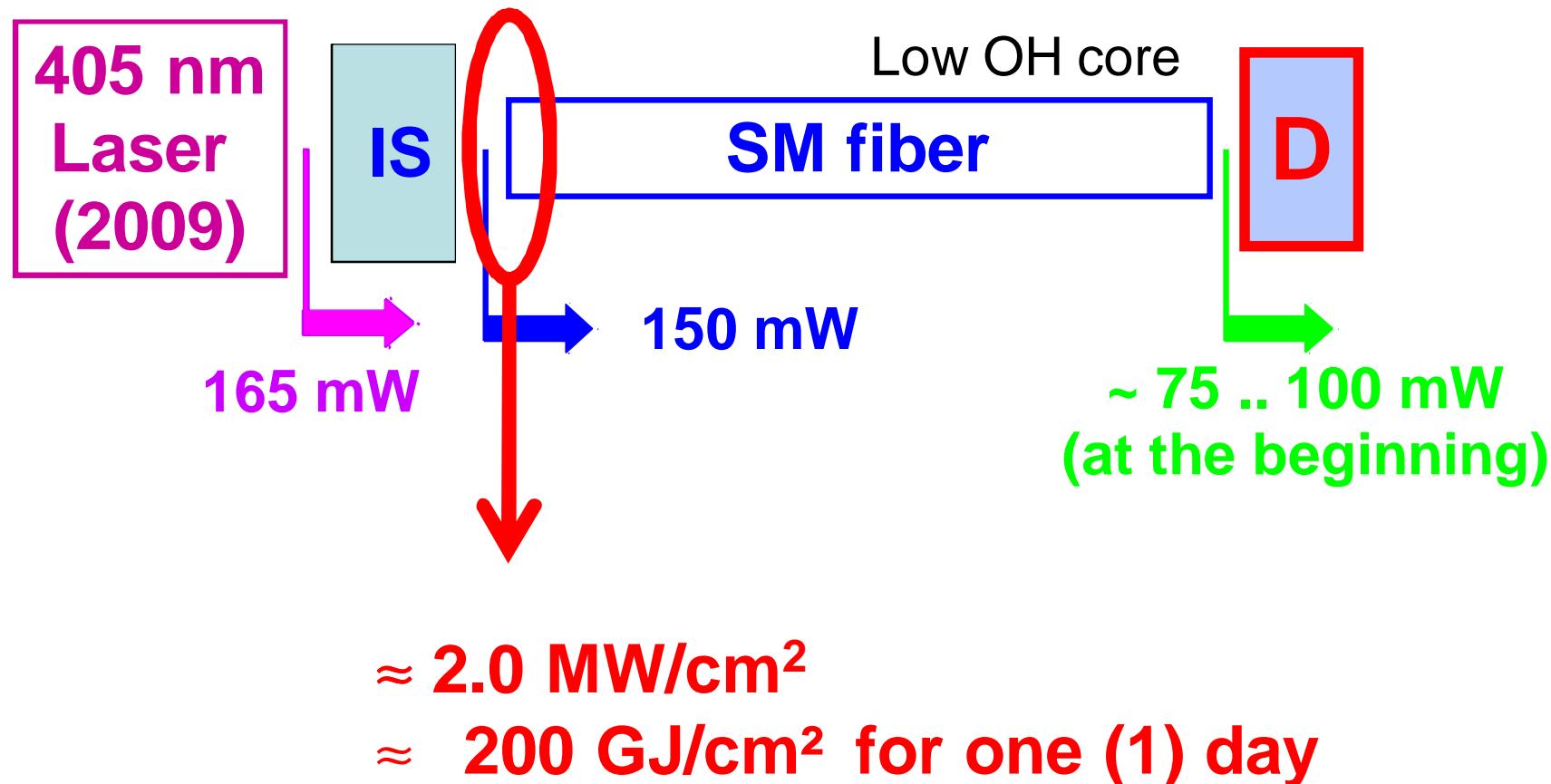
Highest beam quality

Maintaining of polarisation possible

Losses in fiber-optic systems

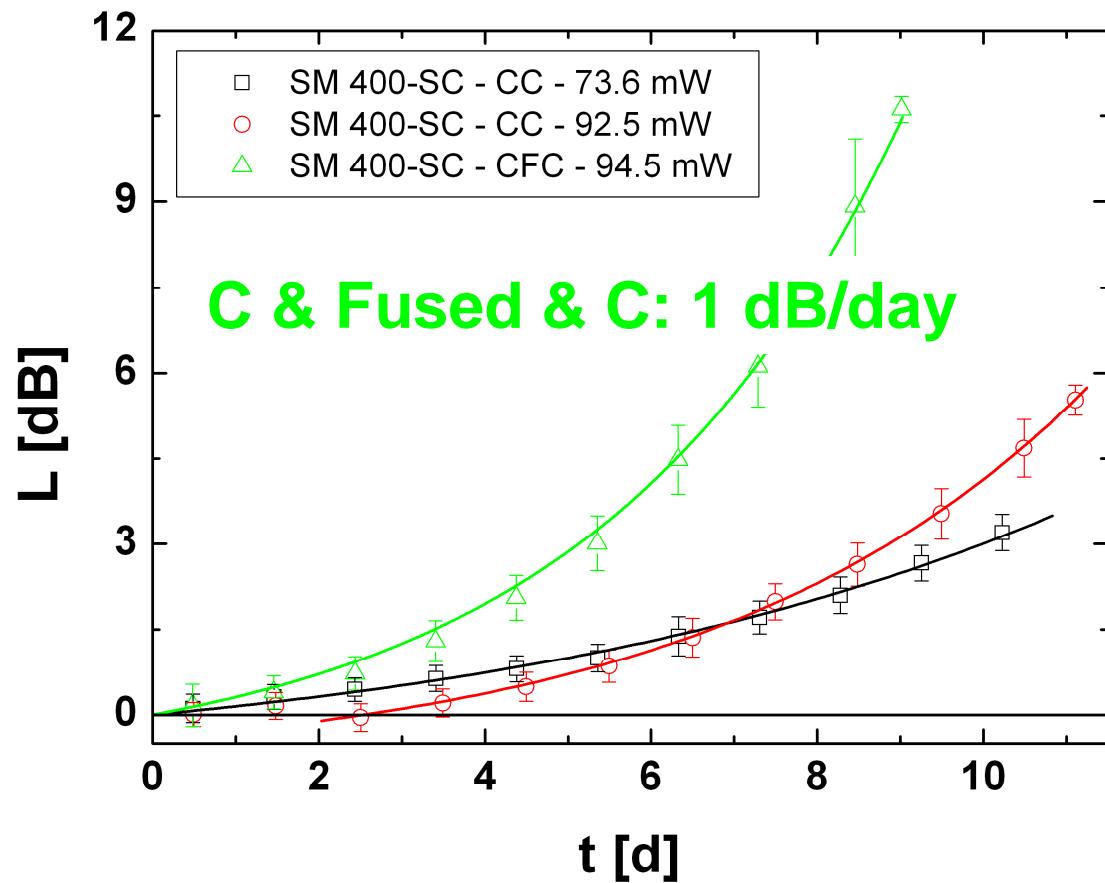


Test set-up 1



Damage at the input surface, only

Transmission loss

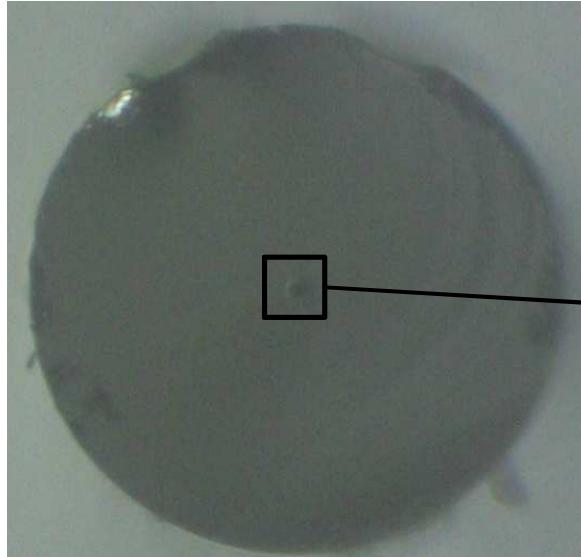


**Power density I_{spot} in laser spot:
2.48 MW/cm²**

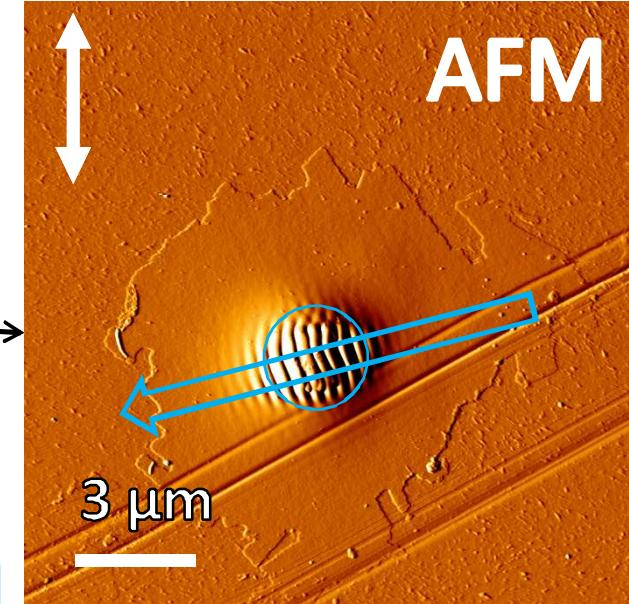
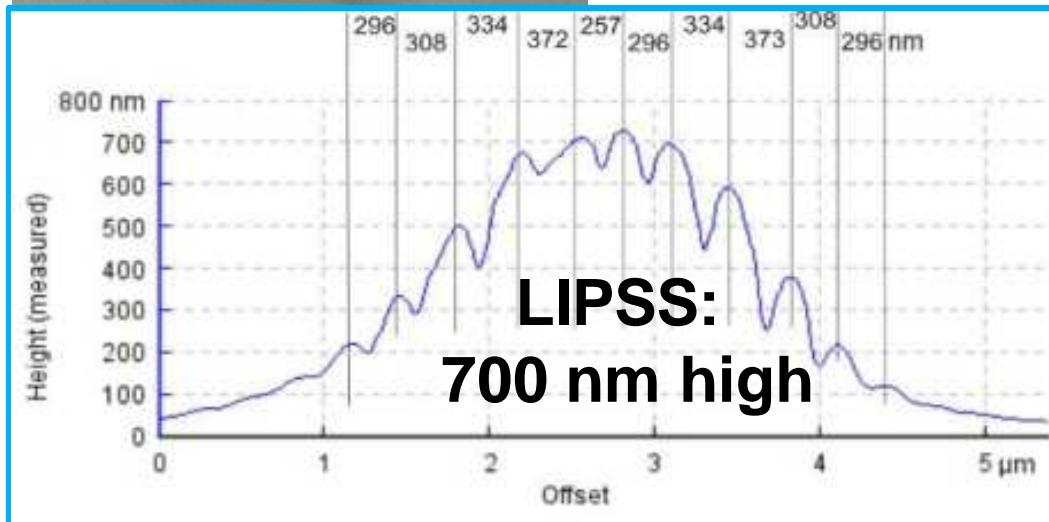
**Cleaved & Clamped:
0.45 dB/day
0.26 dB/day**

**Power density I_{core} in core:
1.6 – 2 MW/cm²**

Analysis of SML damage spot

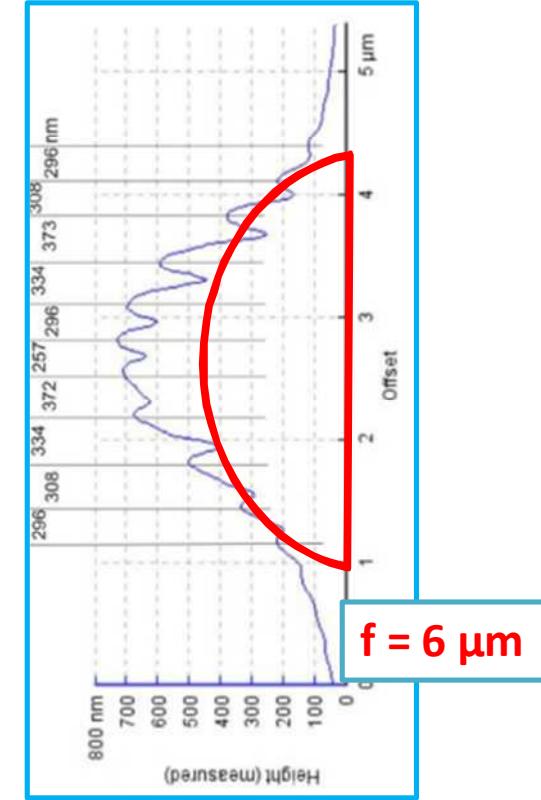
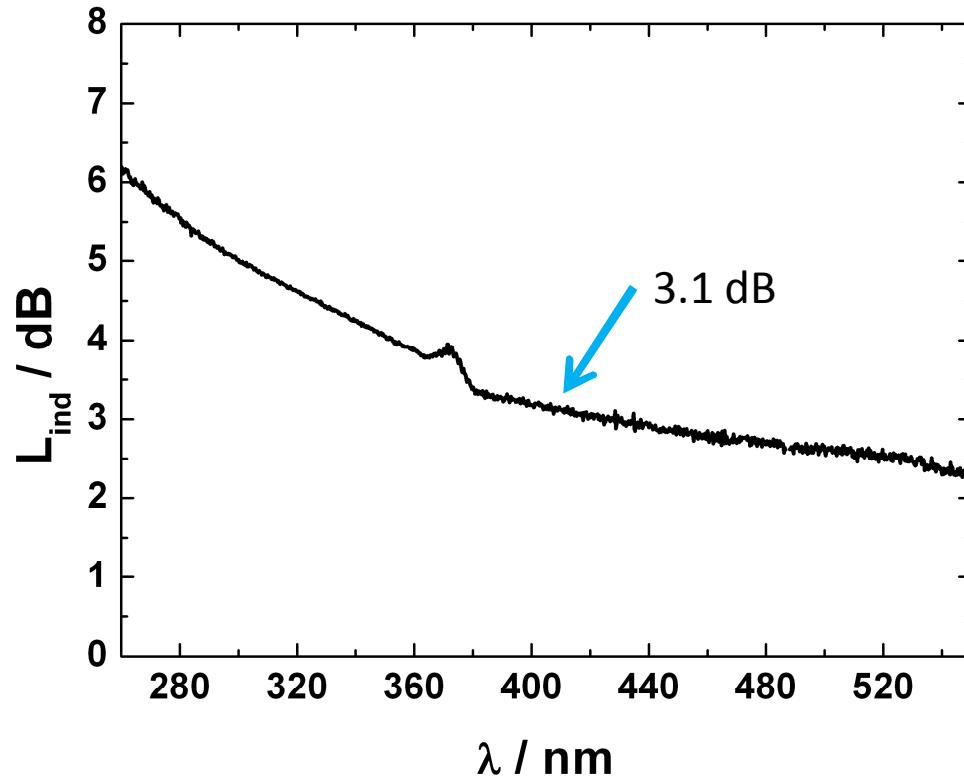


11 days
4.75 dB



Ripple periodicity
of 250 - 400 nm

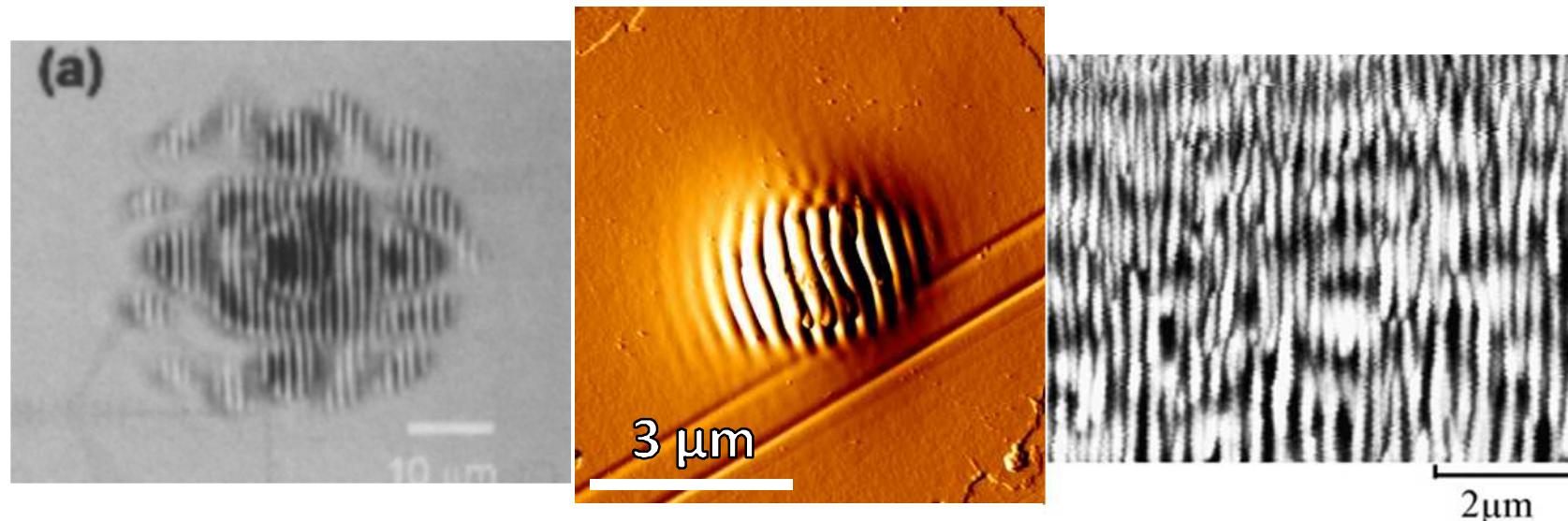
Induced broadband loss



**Broadband focusing
(mismatch \Rightarrow lower coupling efficiency)
and scattering**

LIPSS: comparison with other damaging tests

Theoretical models: Interference or self-organization



Holographic interference
on fused silica

Watanabe W, Itoh K.: Three Dimensional Micromachining with Femto-Second Laser Pulses. In *Recent advances in laser processing of materials*.
Perrière J, Millon E & Fogarassy E (Eds.). 2006. pp. 291-315.

SEM image of ripples
on CaF_2 surface

Varlamova O, Costache F, Ratzke M & Reif J.:
Control parameters in pattern formation
upon femtosecond laser ablation.
Applied Surface Science (2007) 253: pp. 7932-7936.

LIPSS: comparison with other damaging tests

Important parameters for both:
Defects /charges and numbers in the surface
Surface roughness
Intensity
(Hydrogen influence?)

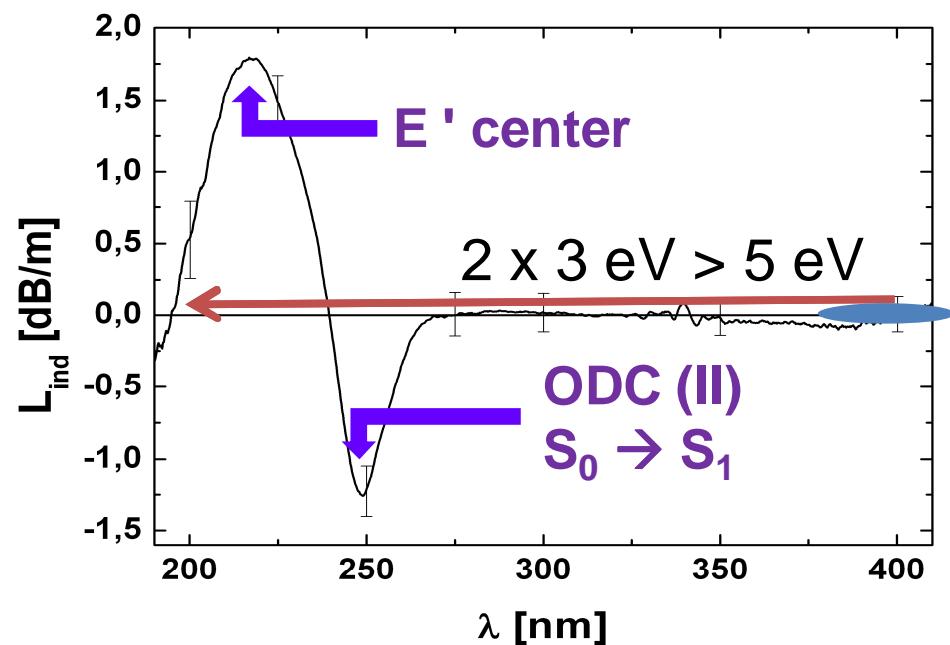
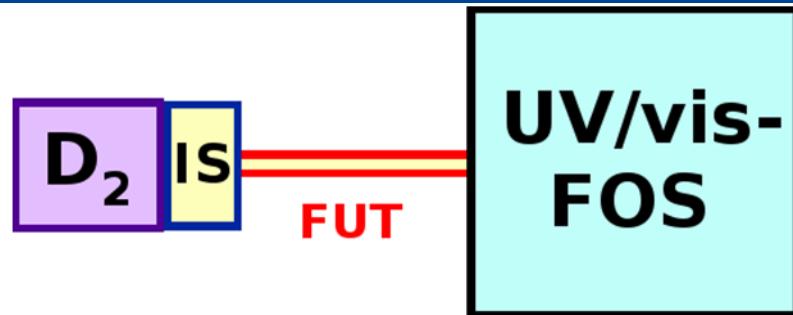
on fused silica

Watanabe W, Itoh K.: Three Dimensional Micromachining with Femto-Second Laser Pulses. In *Recent advances in laser processing of materials.*
Perrière J, Millon E & Fogarassy E (Eds.). 2006. pp. 291-315.

on CaF_2 surface

Varlamova O, Costache F, Ratzke M & Reif J.:
Control parameters in pattern formation
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DUV defects in low-OH core



$$L_{ind}(\lambda) = 10 \cdot \log(I_{before}(\lambda)/I_{after}(\lambda))$$

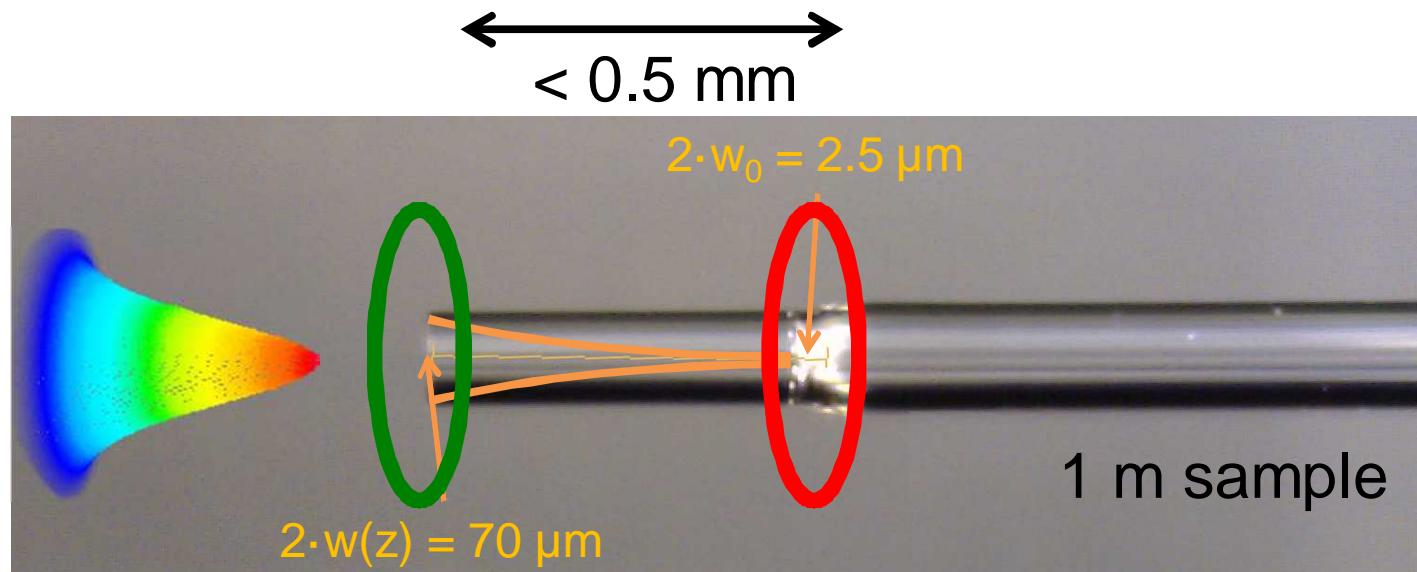
Two-step process:
absorption of photons by
ODC(II) $S_0 \rightarrow T_1$ transition
at 394 nm with ~ 5 dB/km
& transfer to E' centers

Two-photon absorption

→ Defect centers in
the surface, too

Mitigation by intensity reduction

Short cleaved launch fiber LF spliced to SMF end → FDP100
Beam focused through launch-fiber into SMF

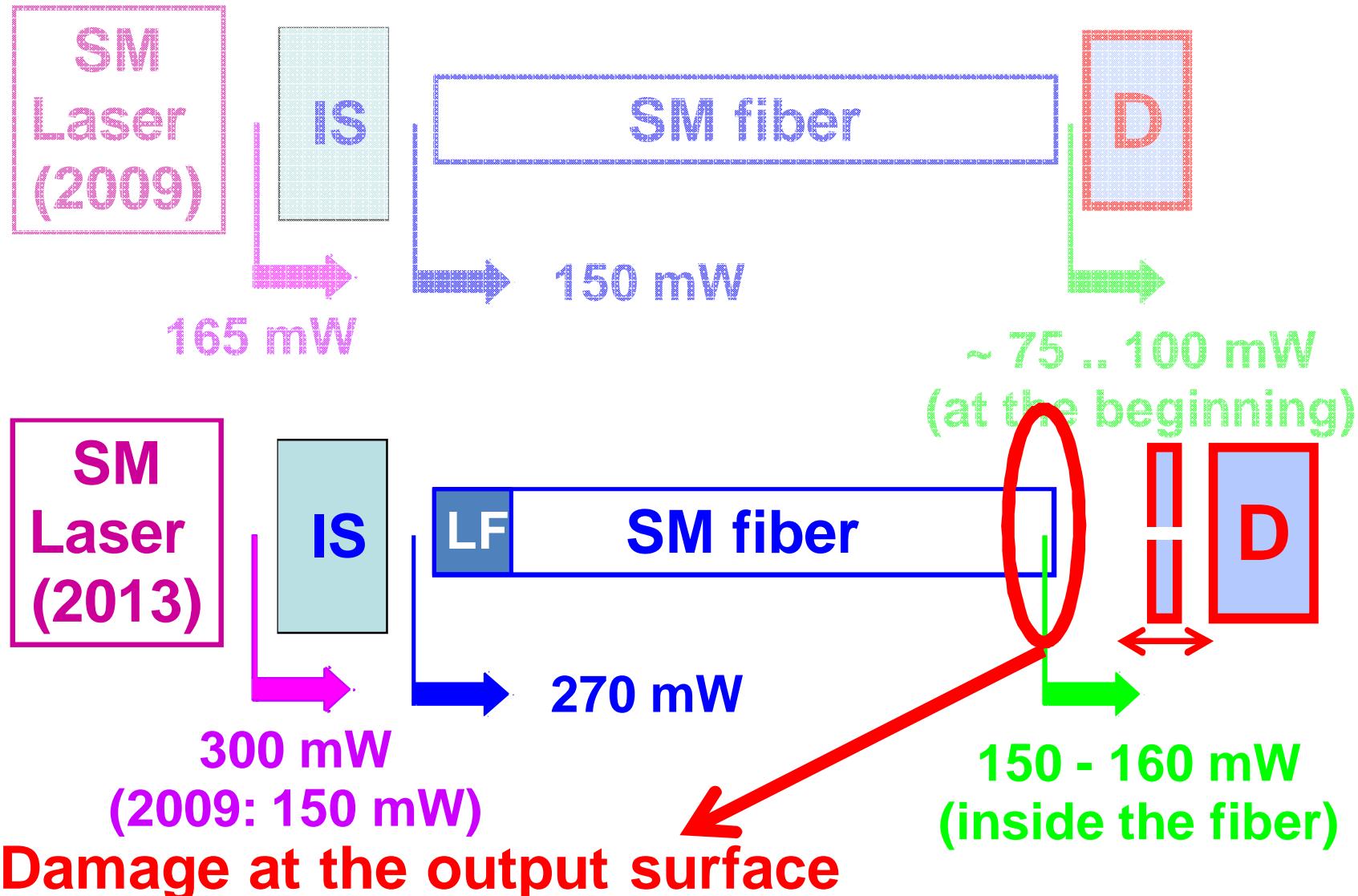


**1.9 – 3.2
kW/cm²**

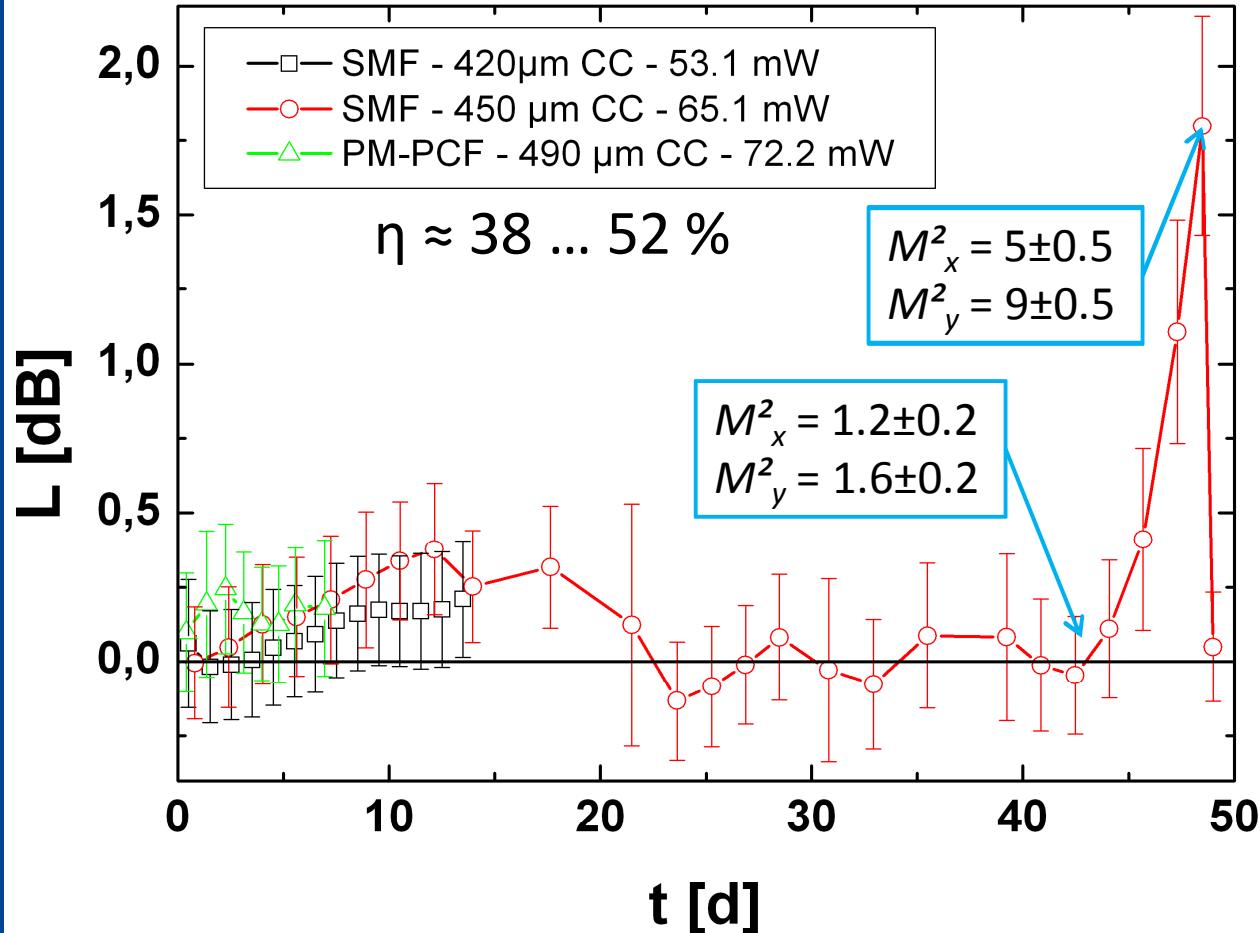
**1.5 – 2.5
MW/cm²**

Patent US4701011 (1987)
Multimode fiber-lens optical
coupler

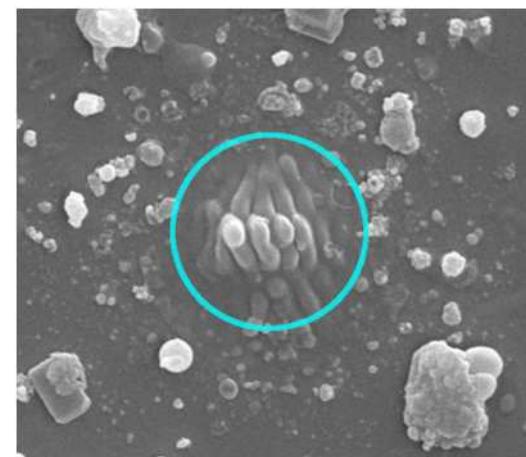
Test set-up 2



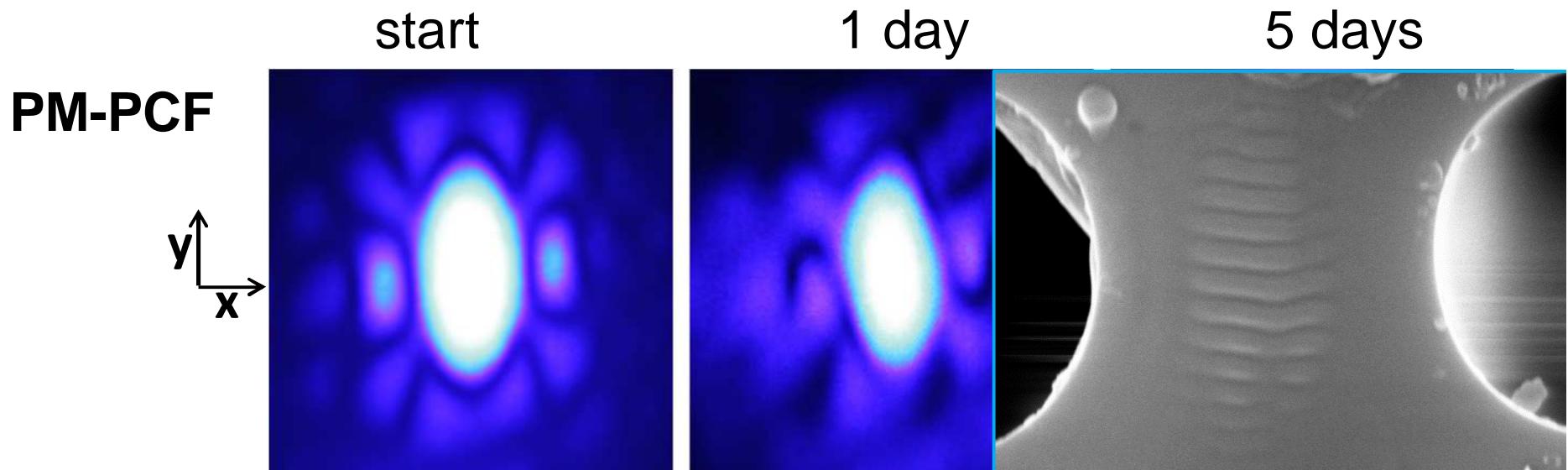
Loss due to output damaging of SMF with launch fiber



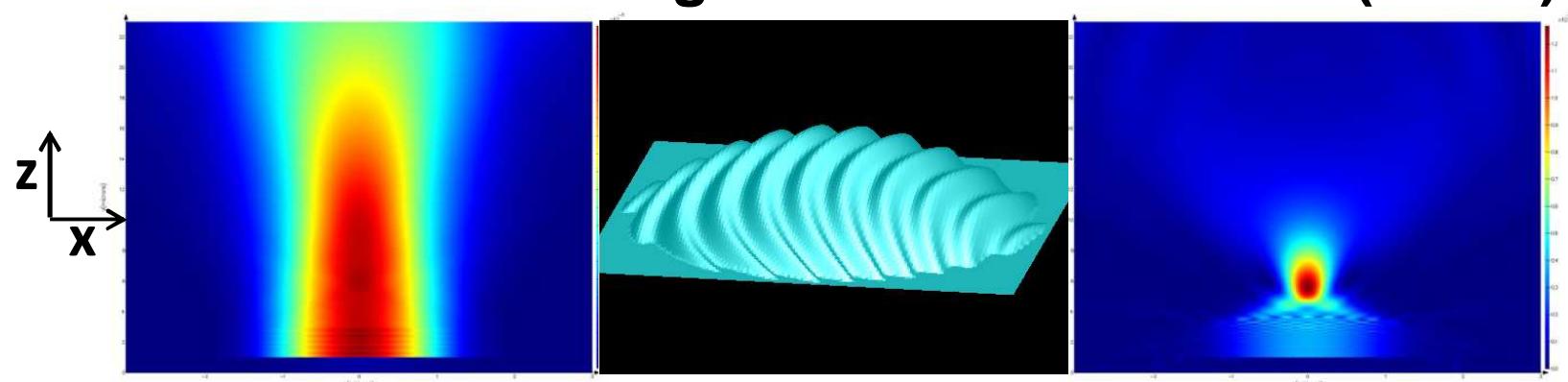
**Power density I_{core}
in core:**
0.8 - 1.3 MW/cm²



Increase of far-field angle (M^2)

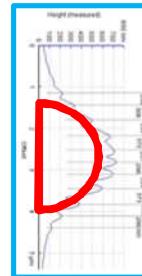


Simulation:
Standard fiber with 700 nm high LIPSS on distal end (FDTD)



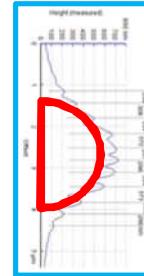
Summary

- Formation of LIPSS (laser-induced periodic surface structures) on input and output surfaces
- Formation of LIPSS on output surface reduces beam quality
- Good agreement between theoretical and experimental results in respect to transmission losses or FF-pattern
- Parameters affecting the growth of LIPSS (two models): presence and numbers of defects/precursors, roughness, power density



Summary and outlook

- Only 75 mW at output surface;
new tests with 150 mW are running,
but not finished for this presentation
- Open:
influence of density of precursors
time-dependent structure of LIPSS
at output surface
damage densities at other wavelengths
- New:
**PM-SM fibers with cleaved angle needed, but
reduction of extinction ratio due to end-caps
other solutions for output surface possible?**



Acknowledgements

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