Mechanisms of radiation induced defect generation in fused silica

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Mechanisms of radiation induced defect generation in fused silica

0. Introduction
1. Previous model of defect generation
2. Measurements of transmission and hydrogen consumption
3. Advanced model of defect generation
4. Advanced model and the change of the refractive index
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0. Introduction

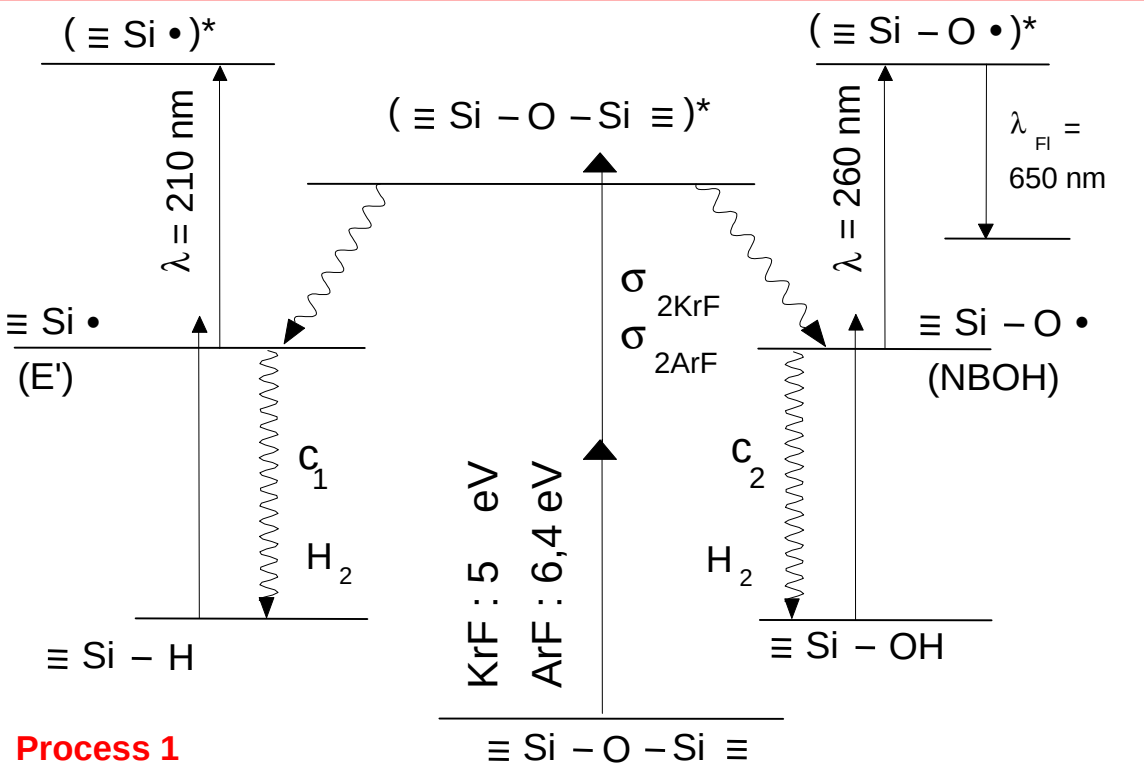
Radiation induced defects:
- absorption
- hydrogen consumption
- refractive index change

Experiments:
- marathon experiments were carried out with the KrF-excimer laser (248nm) and the ArF-excimer laser (193nm)

Measurements:
- transmission
- IR measurements
- raman spectroscopy (hydrogen consumption)
- interferometry (wavefront distortion)

Model of defect generation was developed.

1. Previous Model of Defect Generation



?

Process 2

- **precursors are stretched Si-O bonds**
- **defects are generated by two- and one photon processes**
- **relaxation of the generated defects by reaction with hydrogen**

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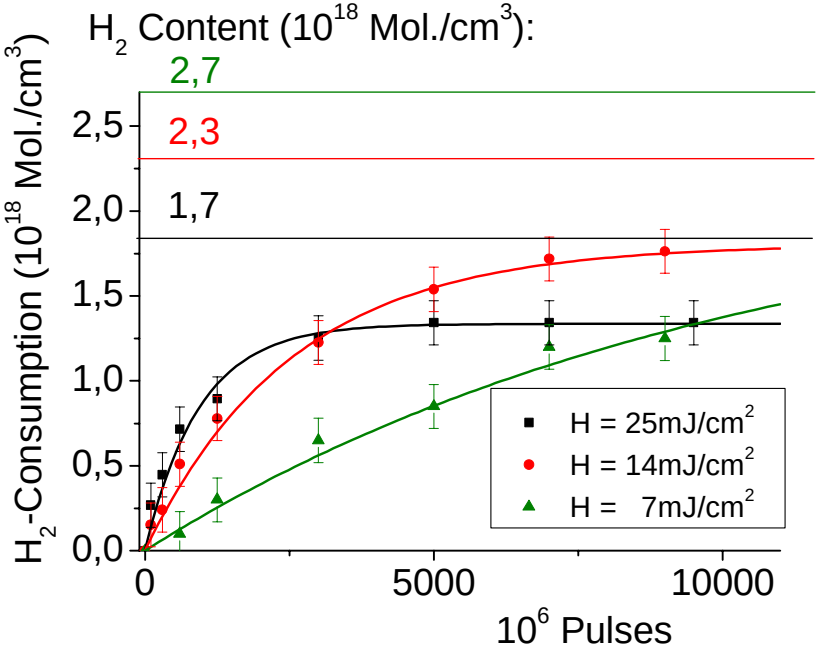
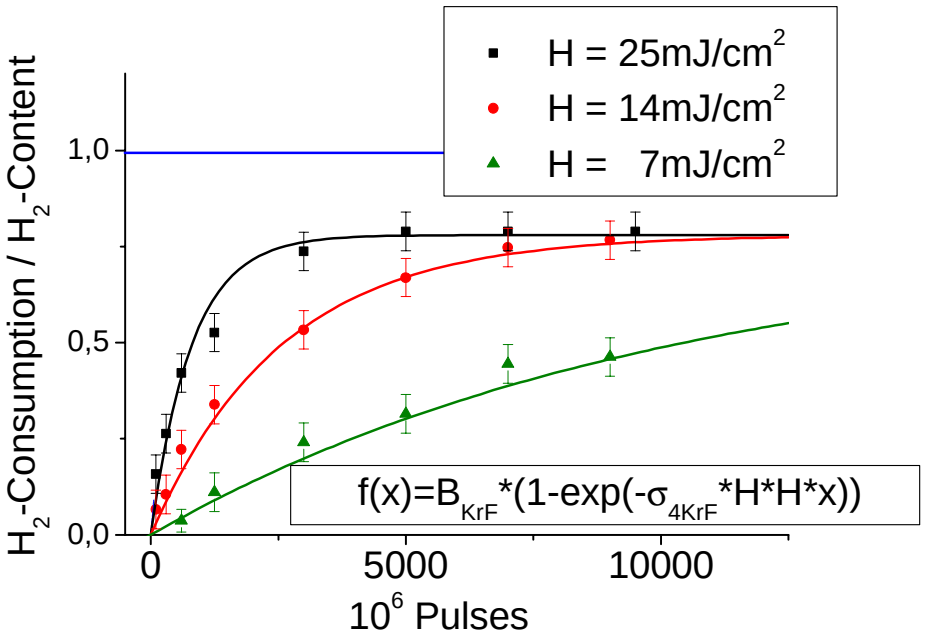
2. Measurement of H_2-Consumption (248nm)

absolute consumption



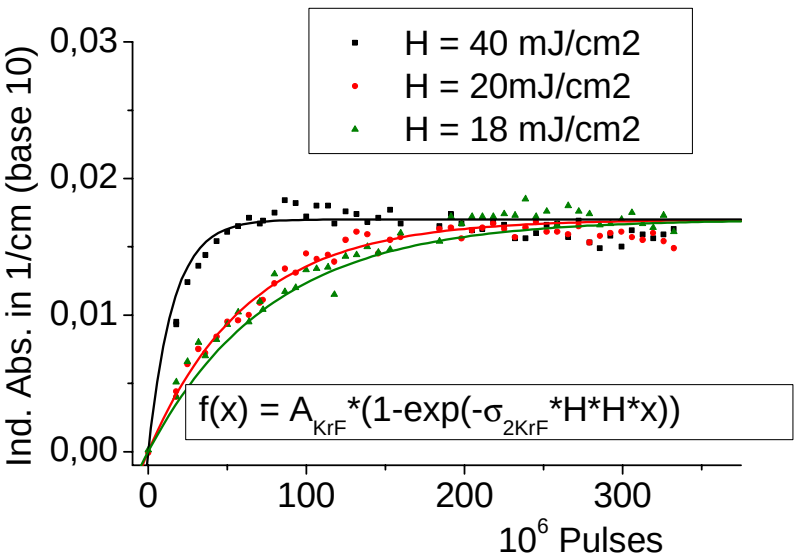
relative consumption



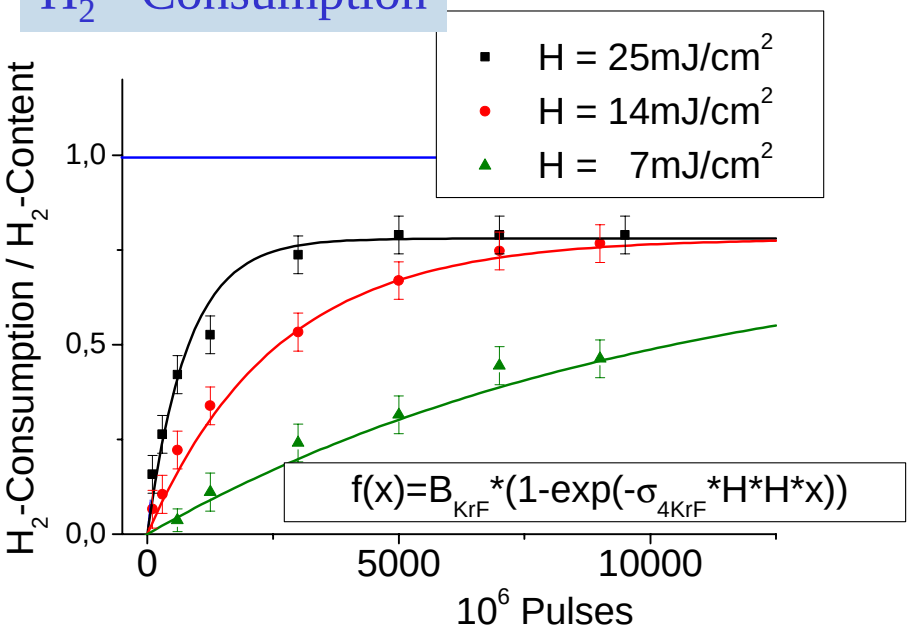
The absolute hydrogen consumption depends on the hydrogen content.
H_2-consumption saturates (saturation value: 0,7..0,8 relative H_2-Consumption)
The relative hydrogen consumption is independend on the hydrogen content.

2. Measurement of Transmission and H_2-Consumption (248nm)

Ind. Absorption



H_2 - Consumption



Extra- low H_2- sample
$H_2 < 10^{16}$ Mol./cm^3
Two Photon Process

Standard sample
$H_2 \approx 2*10^{18}$ Mol./cm^3
Two Photon Process

$\sigma_{2KrF} > 10 * \sigma_{4KrF}$

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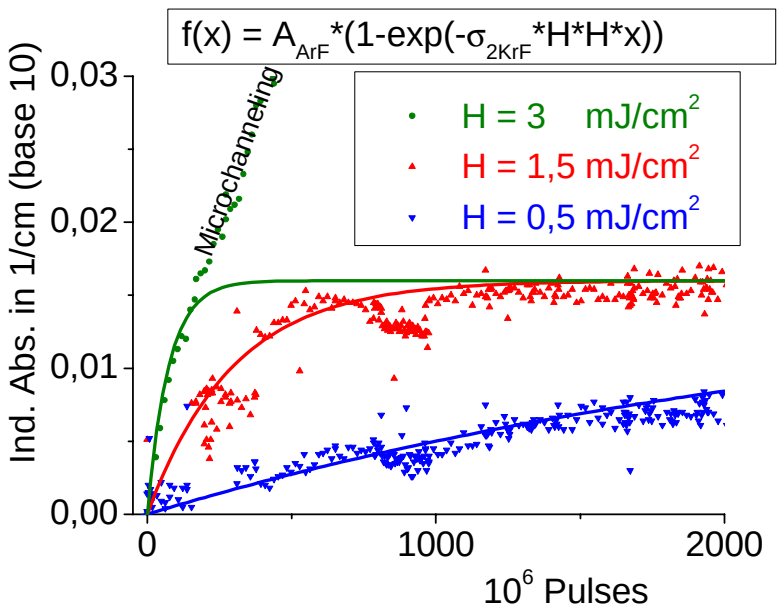
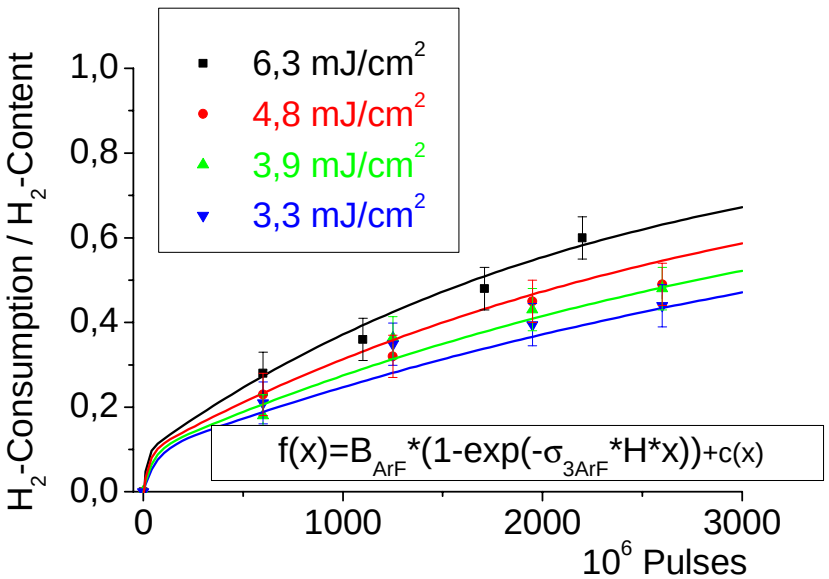
2. Measurement of Transmission and H_2-Consumption (193nm)

Ind. Absorption



H_2 - Consumption



Extra- low H_2- sample
$H_2 < 10^{16}$ Mol./cm^3
Two Photon Process

Standard sample
$H_2 \approx 2*10^{18}$ Mol./cm^3
One Photon Process dominates

Different mechanisms

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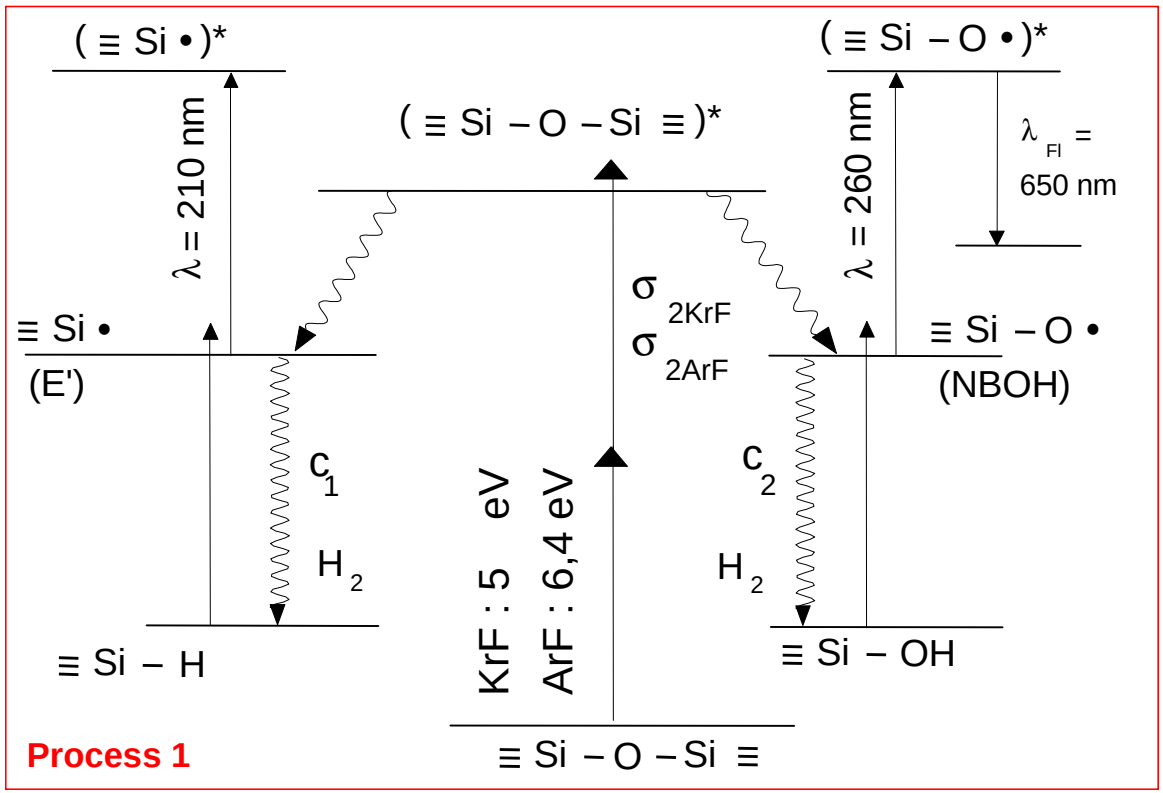
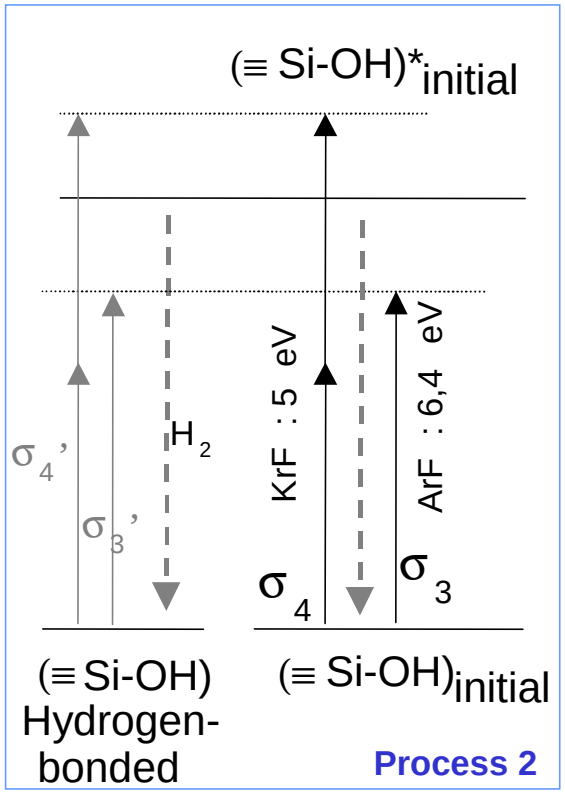
3. Advanced Model of Defect Generation

two fundamental defect generation processes





Process 1: - generation of absorbing defects and consumption of hydrogen ($10^{16}..10^{17}$ /cm^3)

Process 2: - depends on the content of OH and H_2,

- hydrogen consumption saturates due to a radiation induced recovery

- different physically mechanisms in case of irradiation by ArF- and KrF- lasers

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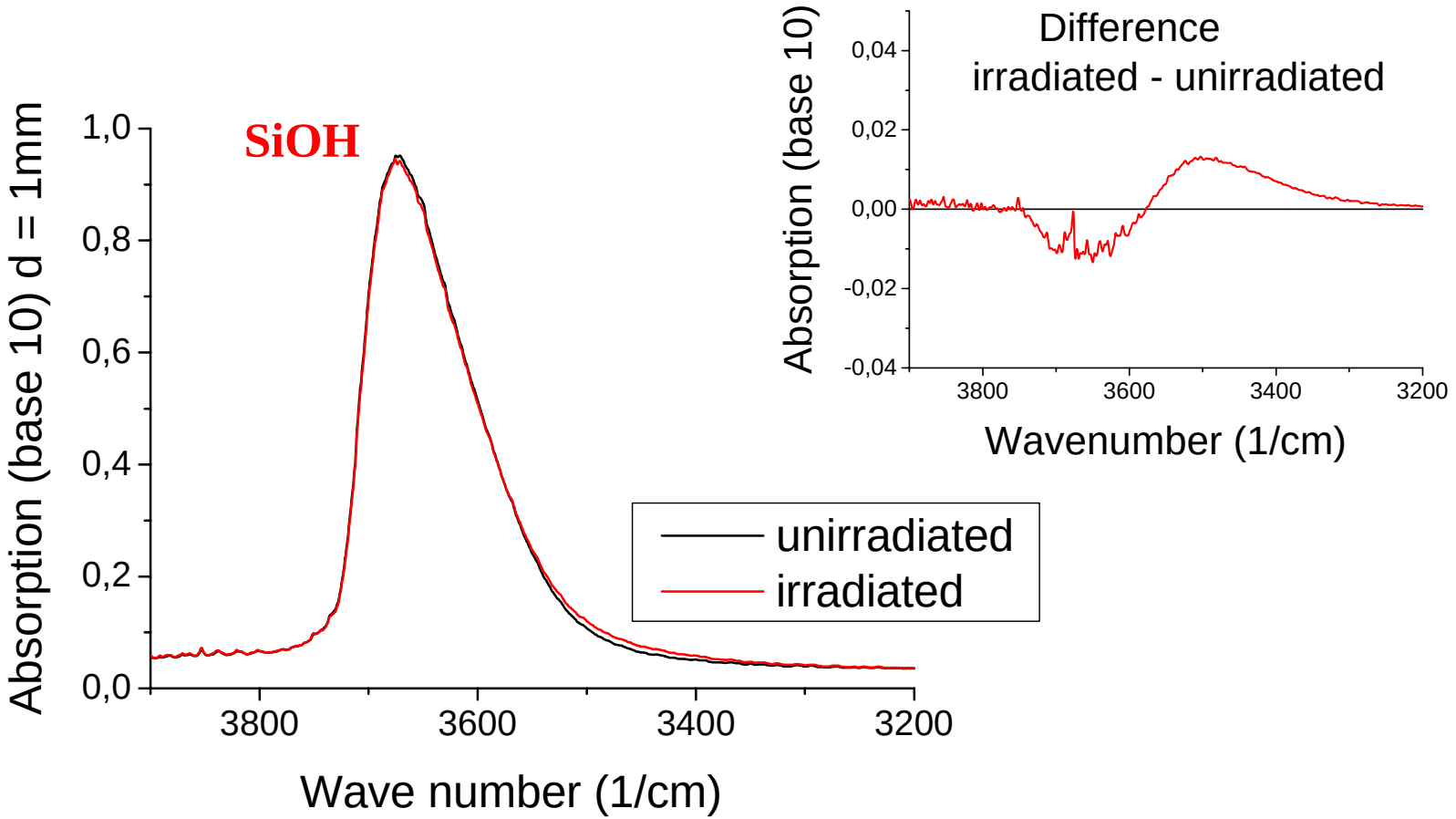
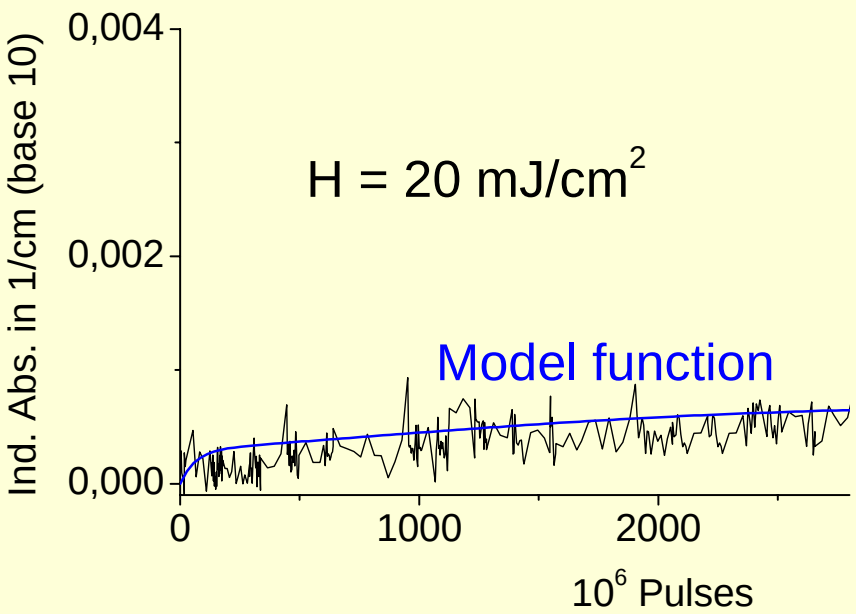
3. Advanced Model of Defect Generation (IR-Spectroscopy)

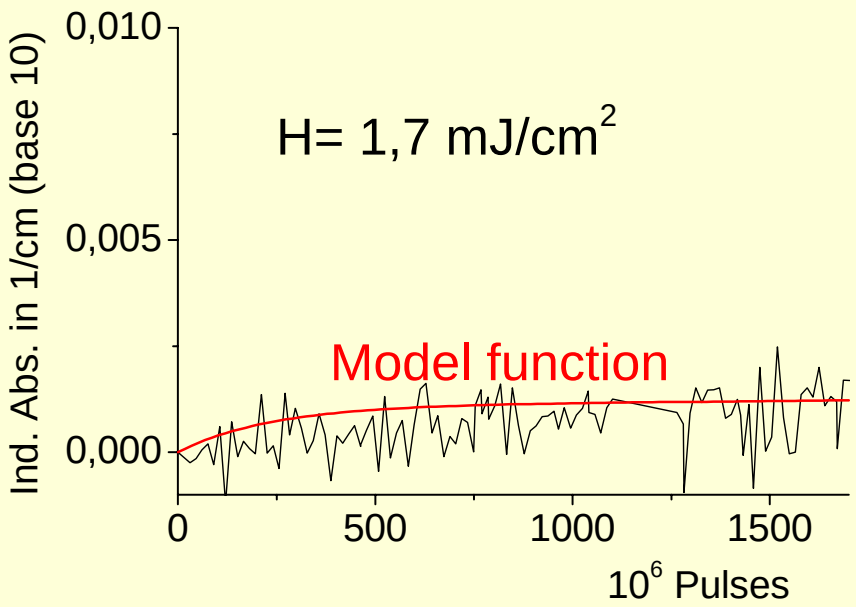


Transformation of (1-2)% of the SiOH (10^{20}/cm^3) corresponds to the H_2-consumption of 1..2*10^{18}Mol./cm^3

3. Advanced Model of Defect Generation (Modelling of Absorption Data)

248nm **Standard Samples** **193nm**





Model function includes the generation of absorbing defects (process 1) and the H_2-consumption due to process 1 and process 2

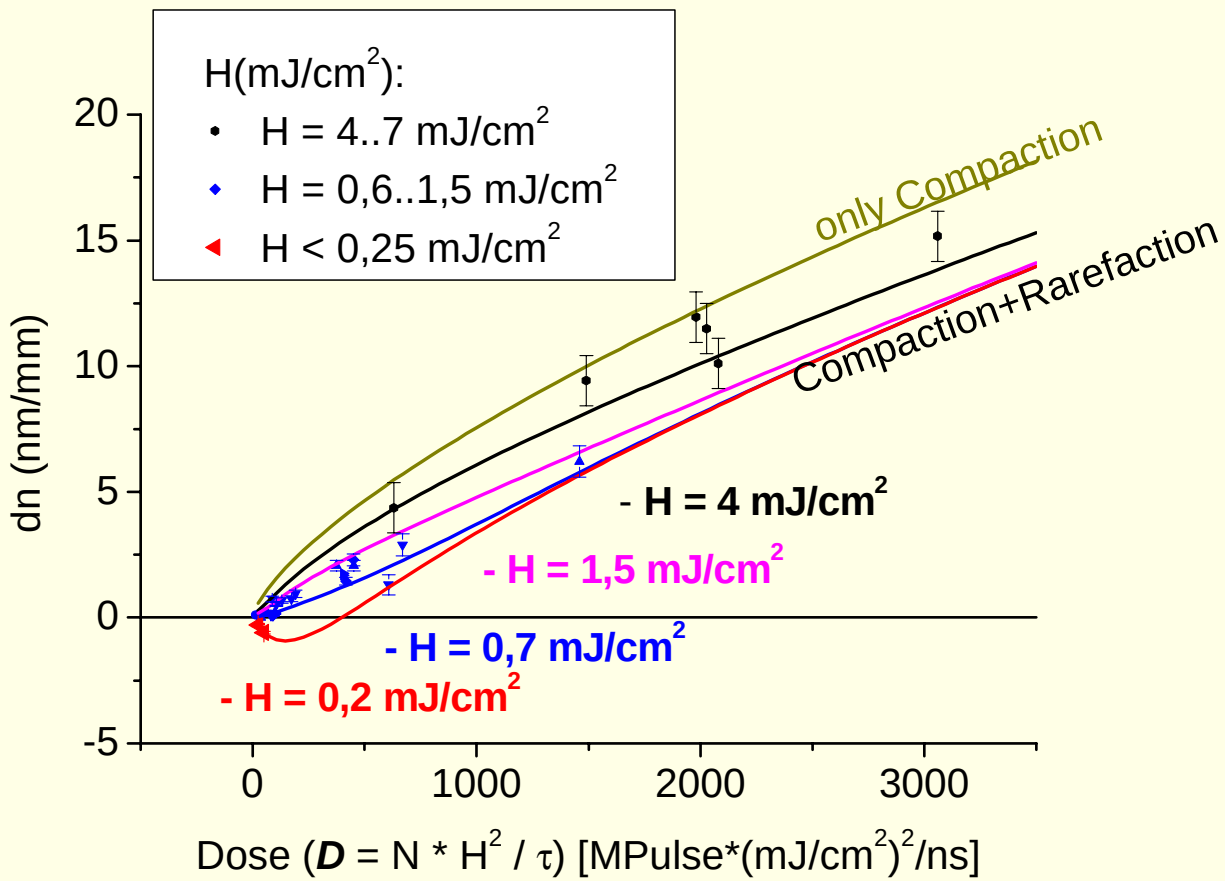
4. Advanced Model and the Change of the Refractive Index

1. **Compaction** due to excitation and relaxation of the network
2. **Rarefaction** due to defect generation processes 1 and 2

	Irradiation by KrF-excimer laser (248nm)	**Irradiation by ArF-excimer laser (193nm)**
Compaction $dn_C > 0$	$\sim(NH^2/\tau)^{0,6..0,7}$ (Schenker)	$\sim(NH^2/\tau)^{0,6..0,7}$ (Schenker)
Process 1 Rarefaction $dn_{R1} < 0$	$f(NH^2/\tau, P)$	$f(NH^2/\tau, P)$
Process 2 Rarefaction $dn_{R2} < 0$	**$f(NH^2/\tau, SiOH, H_2)$**	**$f(NH, SiOH, H_2)$**

$$dn = dn_C + dn_{R1} + dn_{R2}$$

4. Advanced Model and the Change of the Refractive Index (193nm)



In case of a certain, typical H_2-content

dn (D) depends strongly on the energy density of radiation

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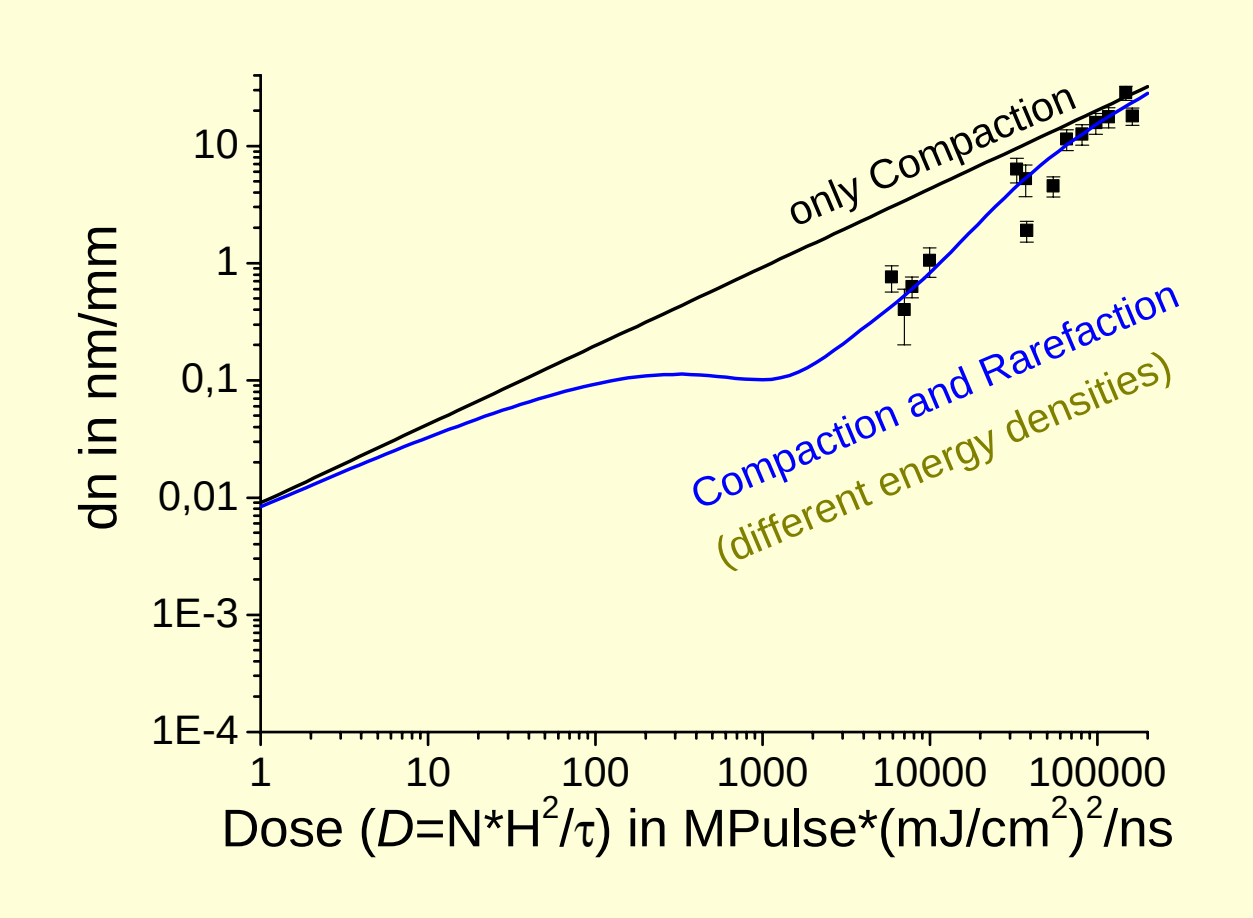
4. Advanced Model and the Change of the Refractive Index (248nm)



In case of a certain, typical H_2-content
dn (D) is independend on the energy density of radiation

5. Summary

Previous Model:

- only process 1
- could not explain discrepancies between measured data of absorption, hydrogen consumption and the decrease of the index of refraction

Advanced Model:

- consists of 2 fundamental processes:
  - Process 1: generation of absorbing defects E‘, NBOHC (small H_2-consumption)
  - Process 2: generation of hydrogen-bonded SiOH (main H_2-consumption)
- good agreement between model calculations and measured data of absorption, hydrogen consumption and the decrease of the index of refraction

What did we learn about the material properties ?

- H_2-consumption: saturates due to a radiation induced recovery
- Rad. Ind. Absorption: saturates due to the saturation of both defect generation processes 1 and 2
- Rarefaction: saturates

Enables the prediction of aging behavior under long time irradiation

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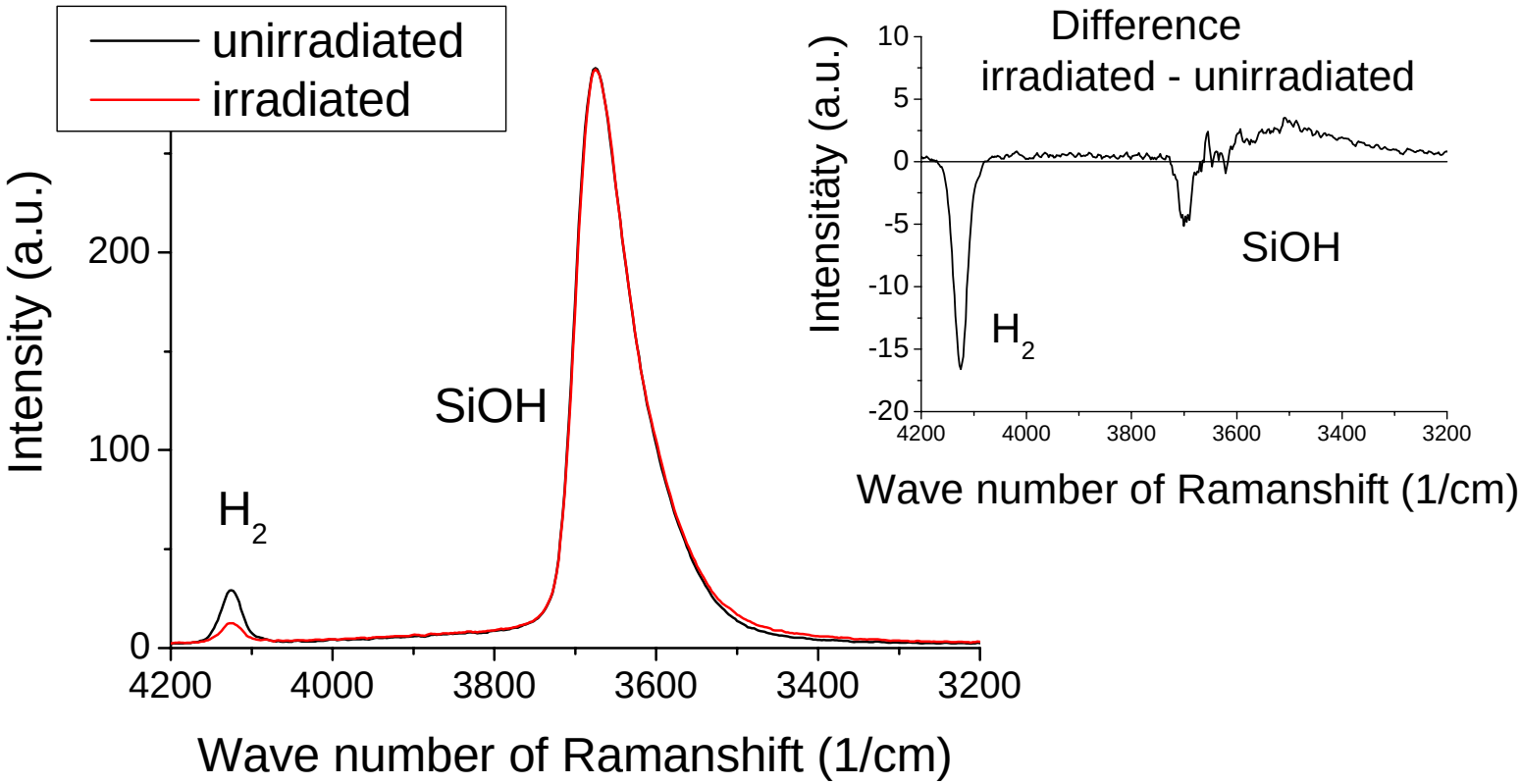
3. Advanced Model of Defect Generation (Raman-Spectroscopy)



Raman measurements show both – H_2 consumption and SiOH transformation