Comparative study of ion beam-irradiation effects on silica and α-quartz: Evidences for excitonic mechanisms

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Introduction

- SiO_2

- Simple composition and structure; Crystalline and amorphous phases
- Adequate for atomistic simulations
- Abundant in nature. Relevant for many technologies

- Irradiation with swift heavy ions:

- They provide EXTREME physical conditions
- Very high excitation densities similar to high power lasers
- Very high local temperatures
- By playing with high energy and heavy mass (SHI) :
- One can go from low electronic excitations (collisions regime) to high electronic excitations (electronic regime)

Experimental

- Samples: SiO_2 6x6x1 mm^3 • Ions: Br 2-40 MeV • J ≈ 10-30 nA
- Beam inhomogeneity < 10 %

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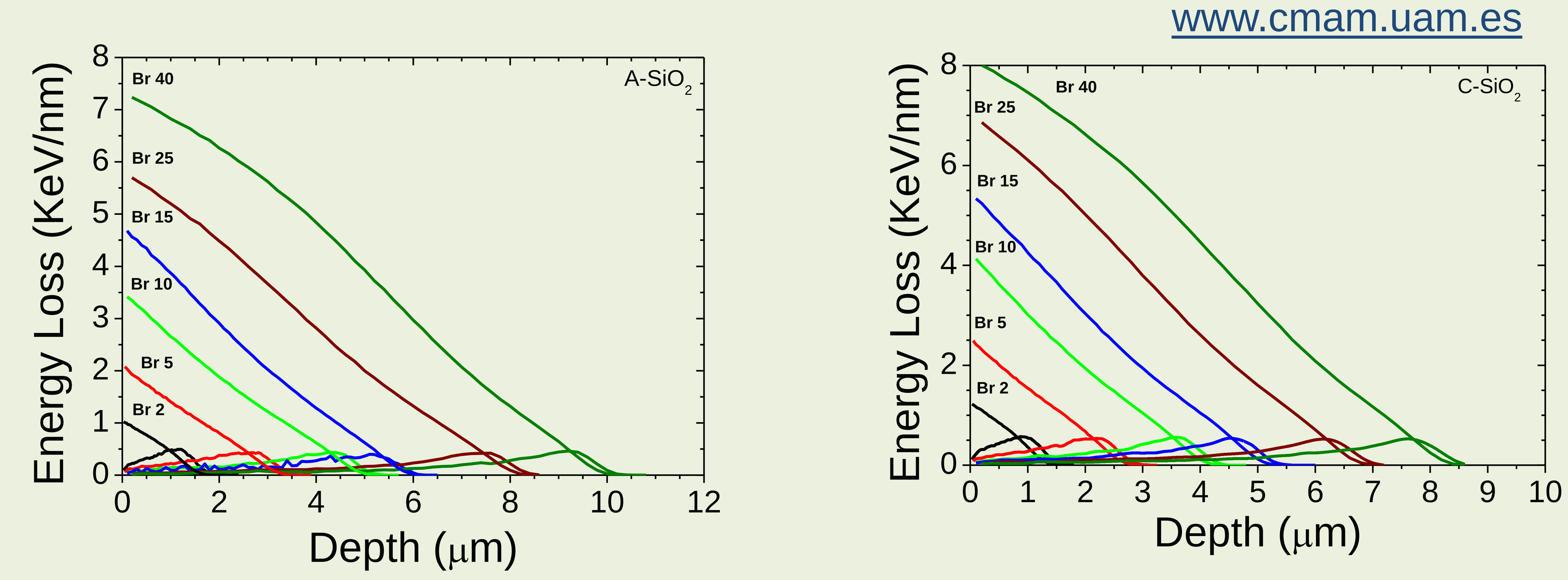
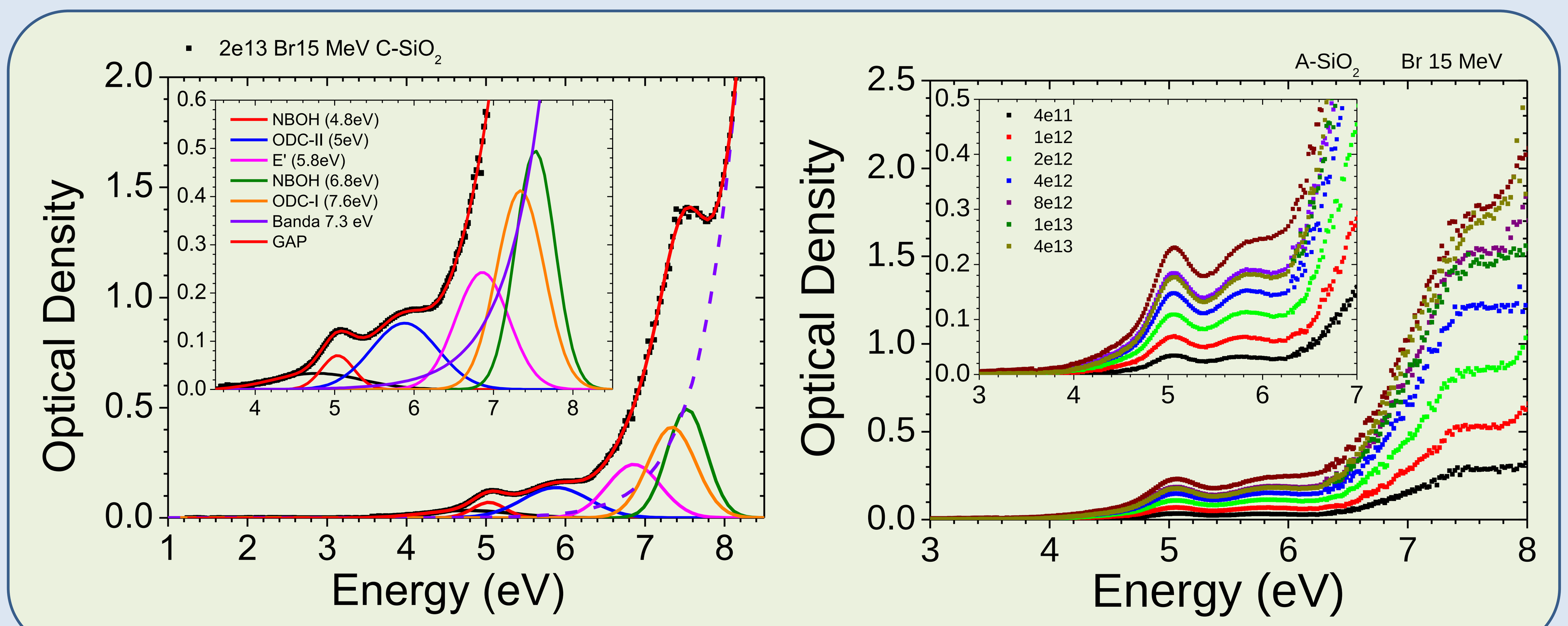
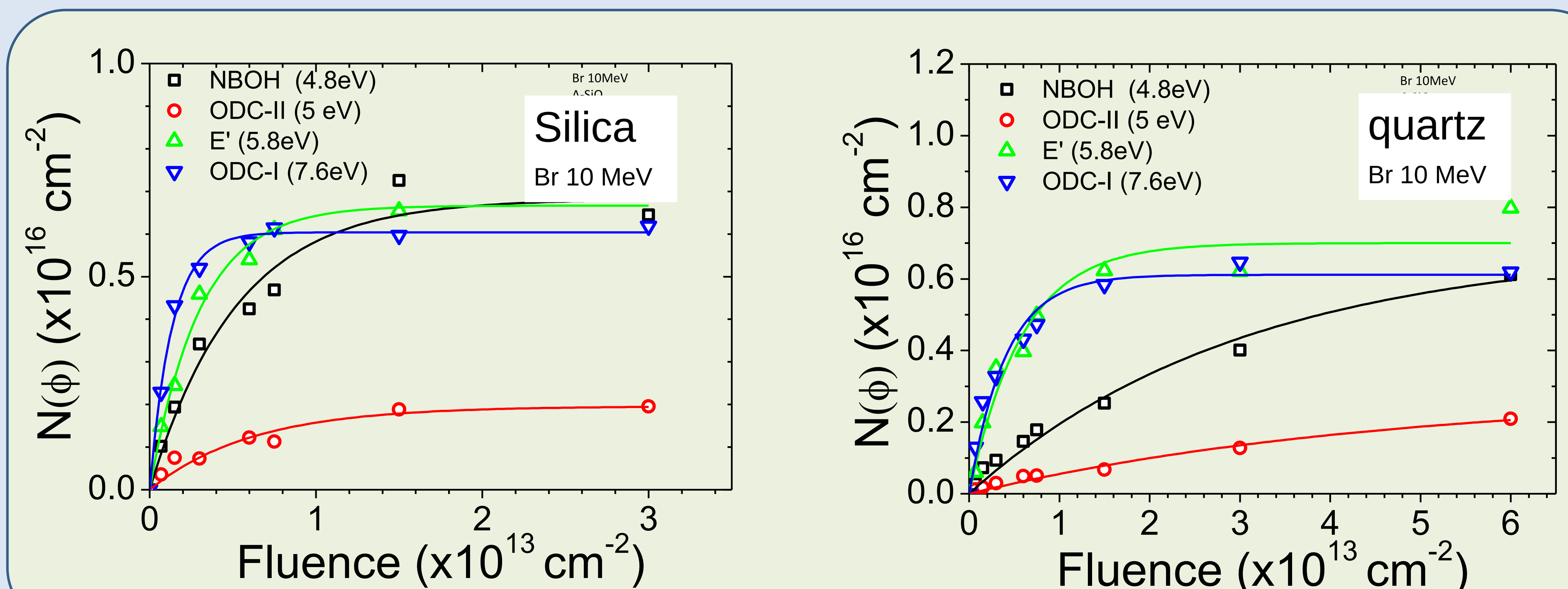






Position (eV)	FWHM (eV)	Oscillator strength	Defect
4.8	1 – 1.2	0.05	NBOHC
5.0	0.35 – 0.4	0.15	ODC-II
5.8	0.8 – 0.9	0.15	E'
6.8	1.7	0.05	NBOHC
7.6	0.5	0.4	ODC-I

Excitonic mechanism

≡Si-O-Si≡ → ≡Si- Si≡ + O_{int} (ODC-I)

≡Si-O-Si≡ → ≡Si-O• + •Si≡ (NBOHC + E')

Ref [4,5]

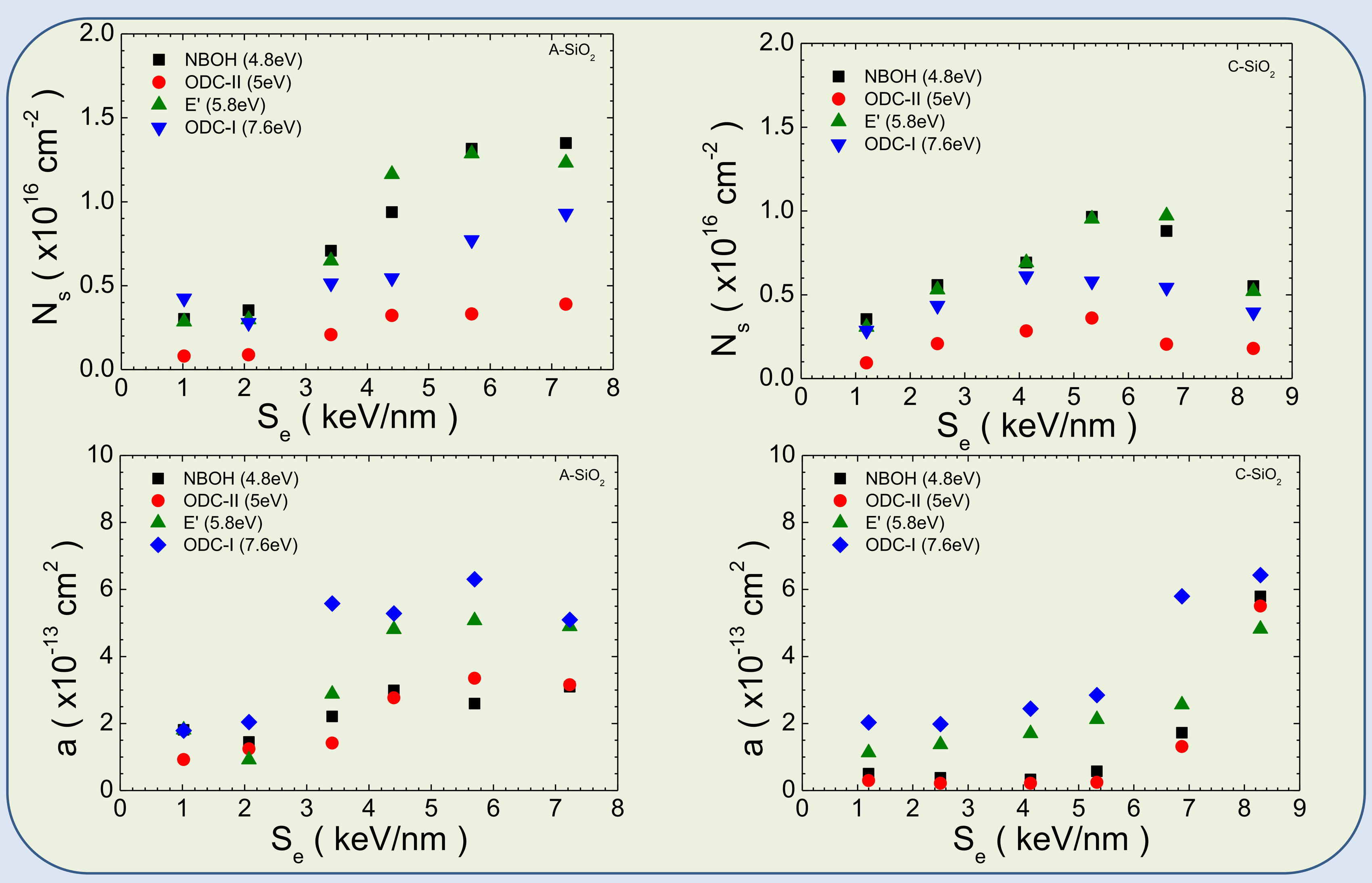
Excitons self trap preferentially in stressed bonds

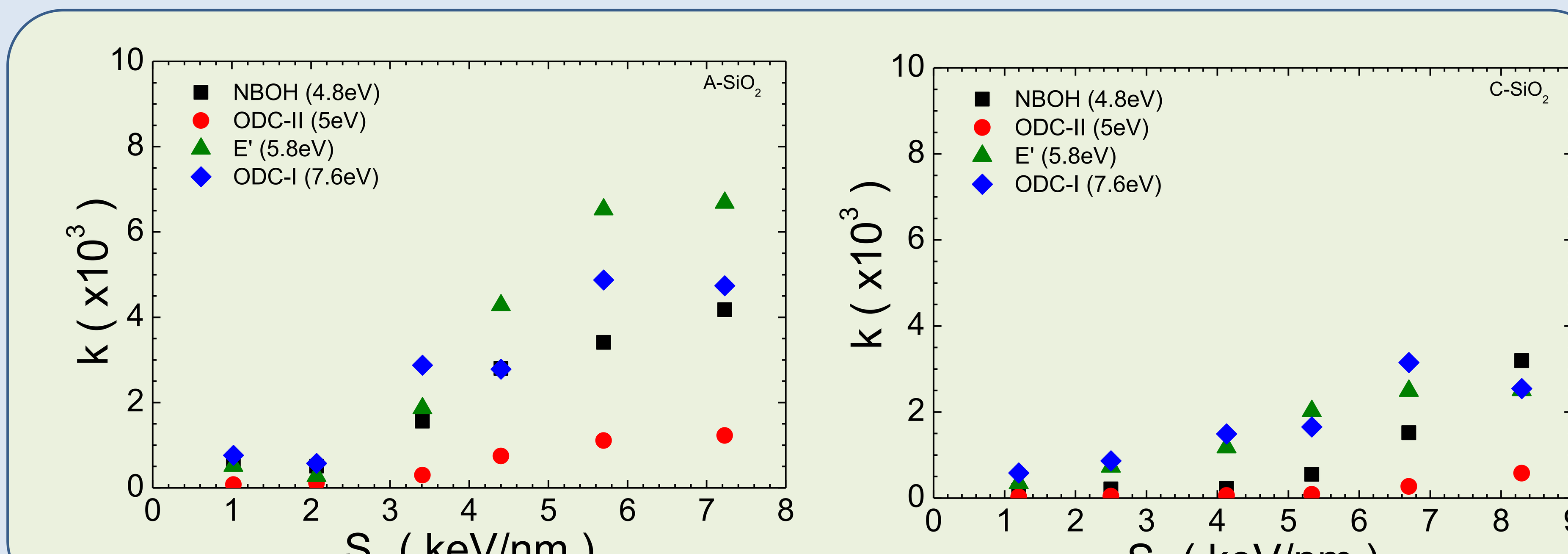
Ref [6,7]

- Growth curves: Poisson-like. Cross-sections σ and saturation values N_S .
- Why the growth reaches a steady state?
  - Saturation or dynamical equilibrium between creation and annealing?
- Dependence of k and N_S on stopping power S_e

$$N(\phi) = N_S\{1-\exp(-\sigma\phi)\}$$

$$k = \sigma\, N_S$$





$$\frac{dc(\phi,z)}{d\phi} = g(S_e) - a(S_e)\,c(\phi,z) \qquad \frac{dN(\phi)}{d\phi} = g(E) - a(E)N(\phi)$$

$$N_S = \frac{g(E)}{a(E)} \quad , \quad \sigma = a(E)$$

g(S_e) and *a(Se)* are overall values for the creation and annihilation rates at a depth *z*, where the stopping power is S_e

Conclusions

- Creation rates show a rather linear dependence on ion energy except at low enough energies where an constant stage is observed
- Higher efficiency for defect creation in silica (role of strained bonds?)
- N_S grows with ion energy up to a maximum value and from then onwards it either saturates (silica) or decreases (quartz). This effect implies an annihilation term.
- Growth kinetics suggest that excitonic mechanisms (probably in synergy with thermal ones) play an important role in defect formation.

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