Local Structure Analysis of Germanium in the Optical Fiber

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The optical fiber is essential to the mass high-speed optical communication. Optical signals are transmitted in the optical fiber core region by the waveguide structure. To control the refractive index, GeO_2 and/or F are doped to SiO_2 glasses. The transmission losses, relating to the glass structure, are required to be suppressed to low levels. They, however, increase with increasing the GeO_2 concentration. We, therefore, have studied the GeO_2-SiO_2 glass structure with focus on the local structure of Ge against the GeO_2 concentration.

The figure shows XANES spectra of the GeO_2-SiO_2 glasses with different GeO_2 concentrations. The spectral shapes are quite similar to each other but the absorption edge is shifted to the higher energy side according to the refractive index difference (Δn).

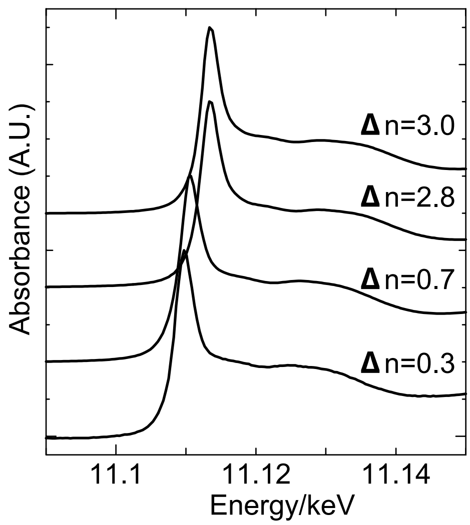

Figure The Ge-K XANES spectral change with the reflective index difference (Δn) of GeO_2-SiO_2 glasses.

LOCAL STRUCTURE ANALYSIS OF GERMANIUM IN THE OPTICAL FIBER

1. Introduction
2. Theoretical analysis of Ge XANES
3. Conclusion

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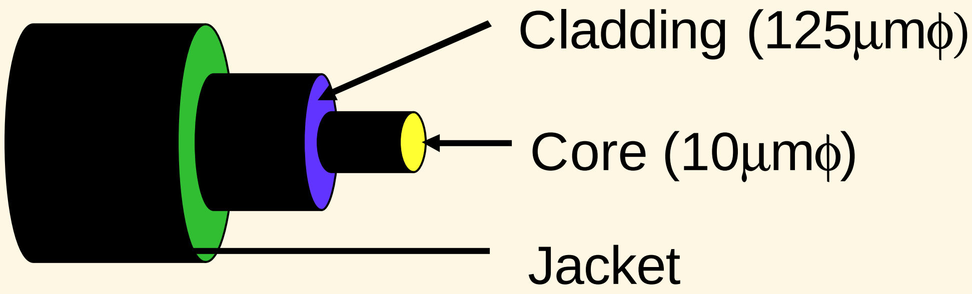
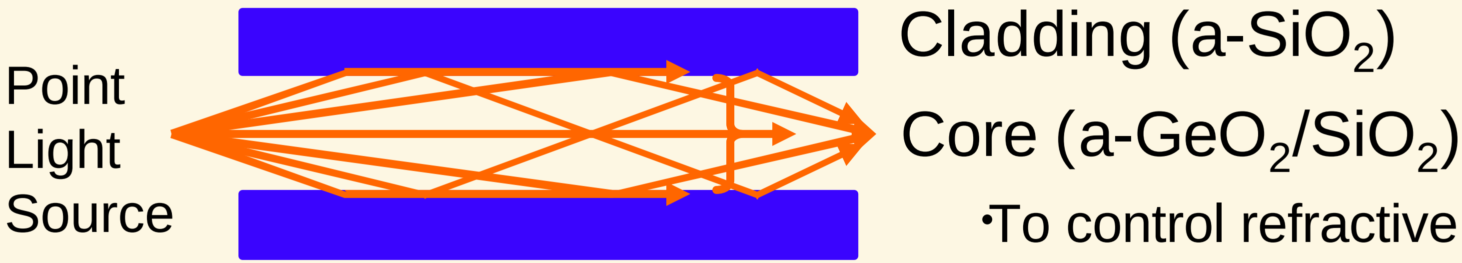
Optical Fiber Cable

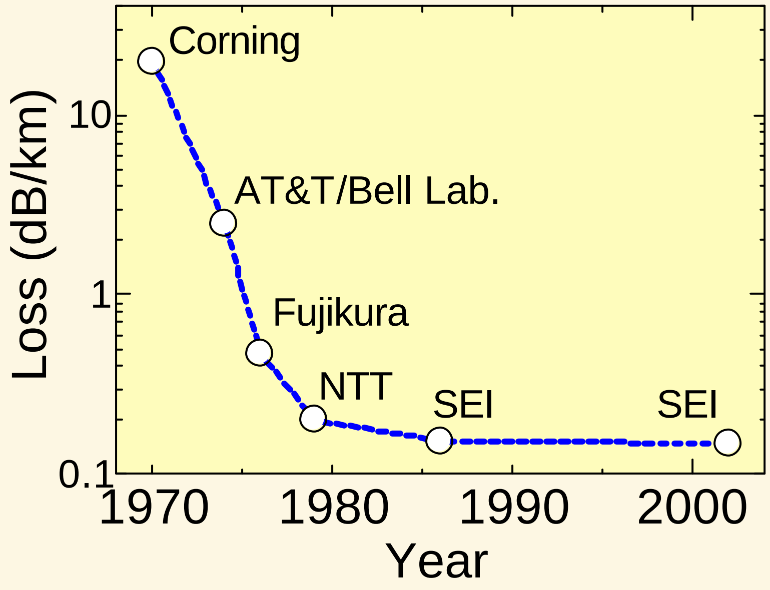


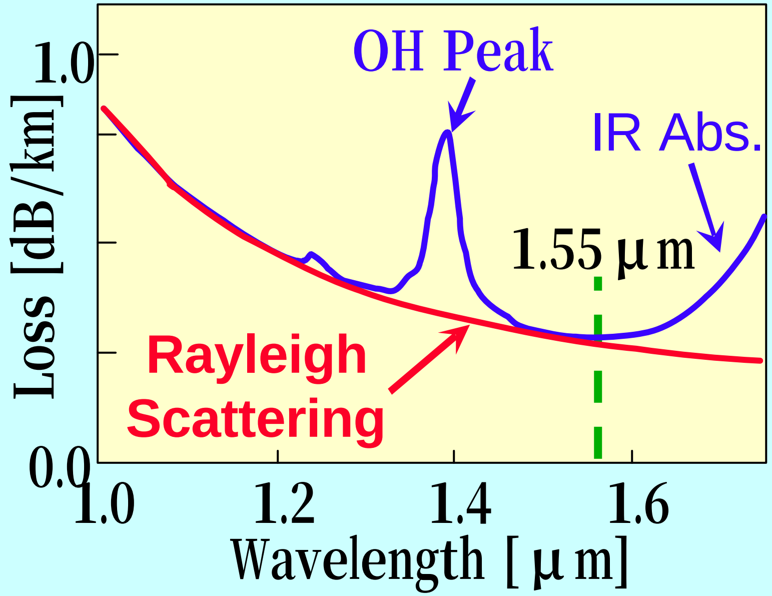


- To control refractive index

Waveguide Structure

Lowering the Loss of Optical Fiber





Rayleigh Scattering → **Structure**

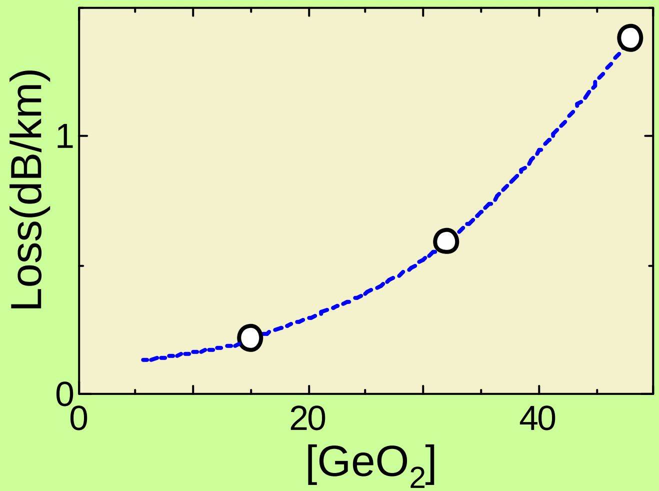
IR Absorption → Impurities

Limit

Structural analysis method for GeO_2 doped SiO_2 glass

GeO_2 doped SiO_2 glass

Loss $\propto$ $[GeO_2]$



$[GeO_2]$ ⟺ **Structure**

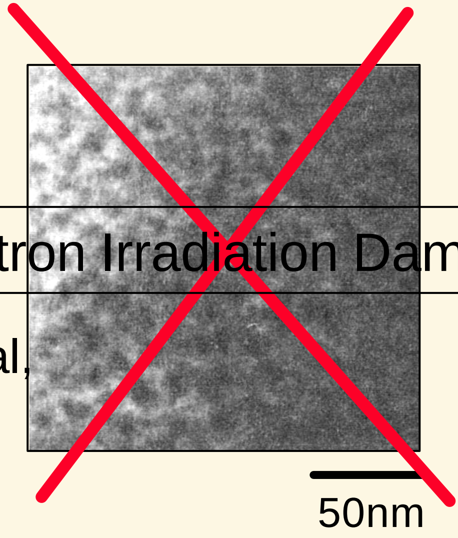
Ge metal cluster observed by TEM

Useful Method?

Verification

XAFS Method

Ge metal cluster was denied.

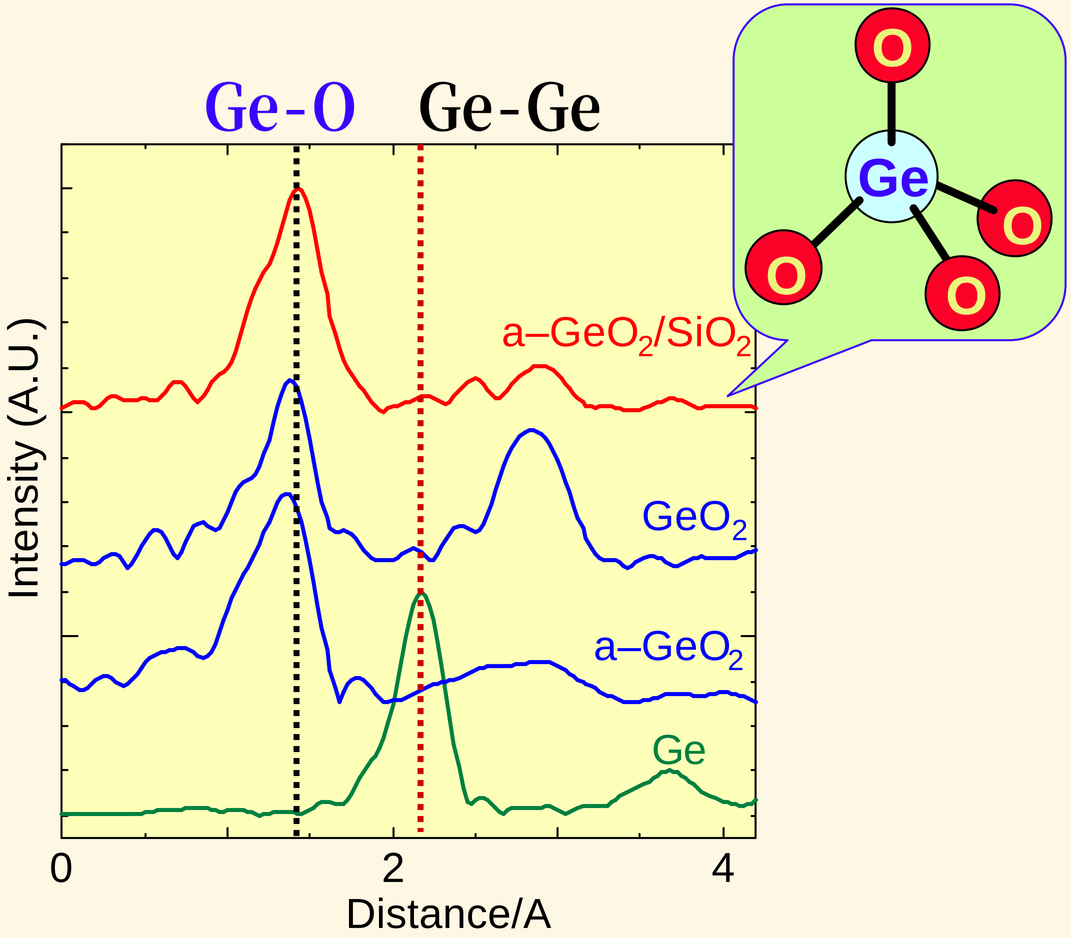


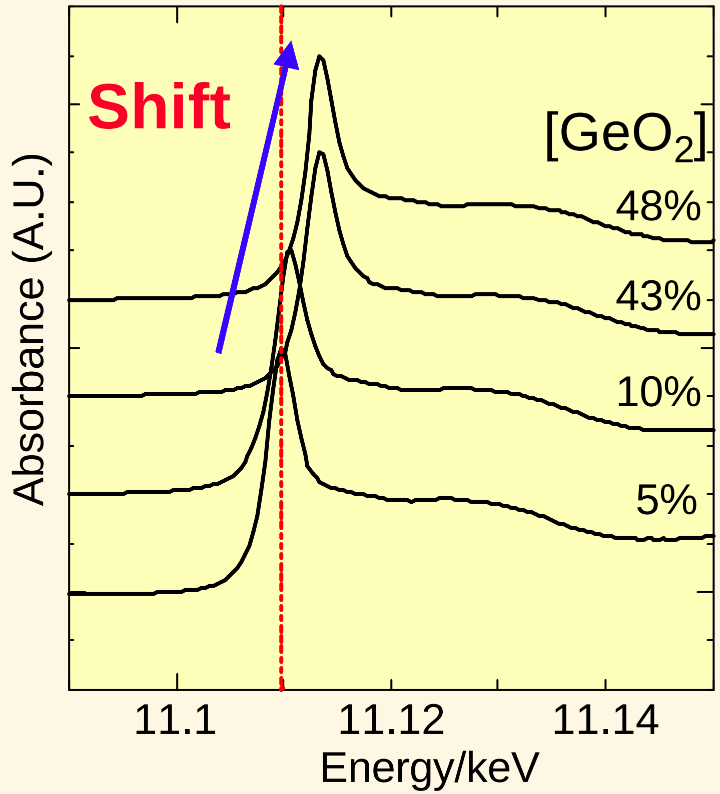
Electron Irradiation Damage

Ishikawa,Iihara et.al,
JSAP 2001 Spring

H.Hosono et.al.,
J.Appl.Phys 80,3115(1996)

Experimental Results of XAFS Method





- 1st Neighbor：Oxygen, Coordination Number～4
- XANES Peak：Shift to Higher Energy by [GeO_2]

Theoretical analysis of XANES energy shift

1. Selection of XANES analysis method
2. XANES simulation for some models

Selection of analysis method

Identification of XANES

- Fingerprinting Method → Preparation of Standard Specimen is impossible
- Simulation Method

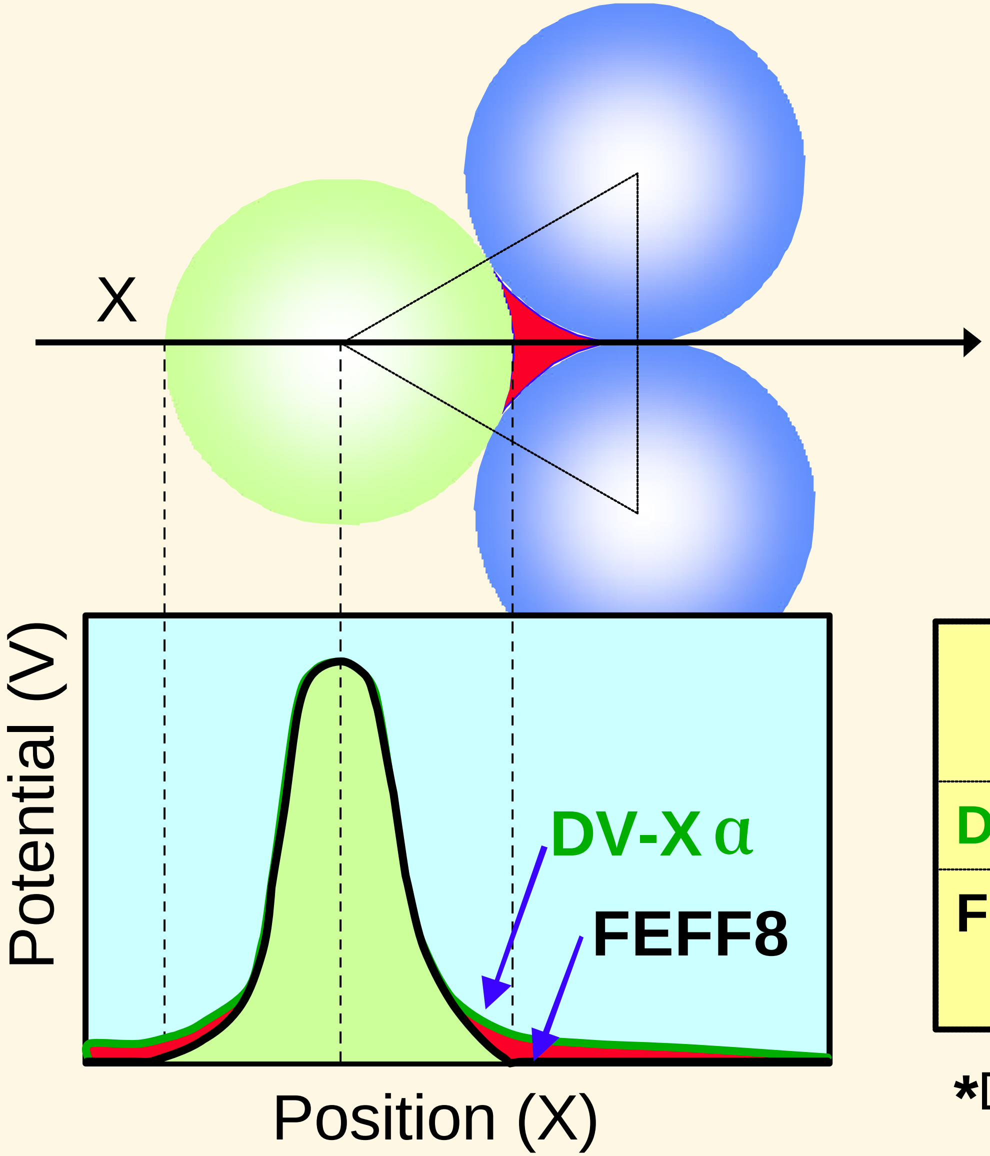
Selection of Calculation Method

FEFF8
DV-X α → Test calculation for GeO_2, Metallic Ge

Object

- XANES Energy Shift

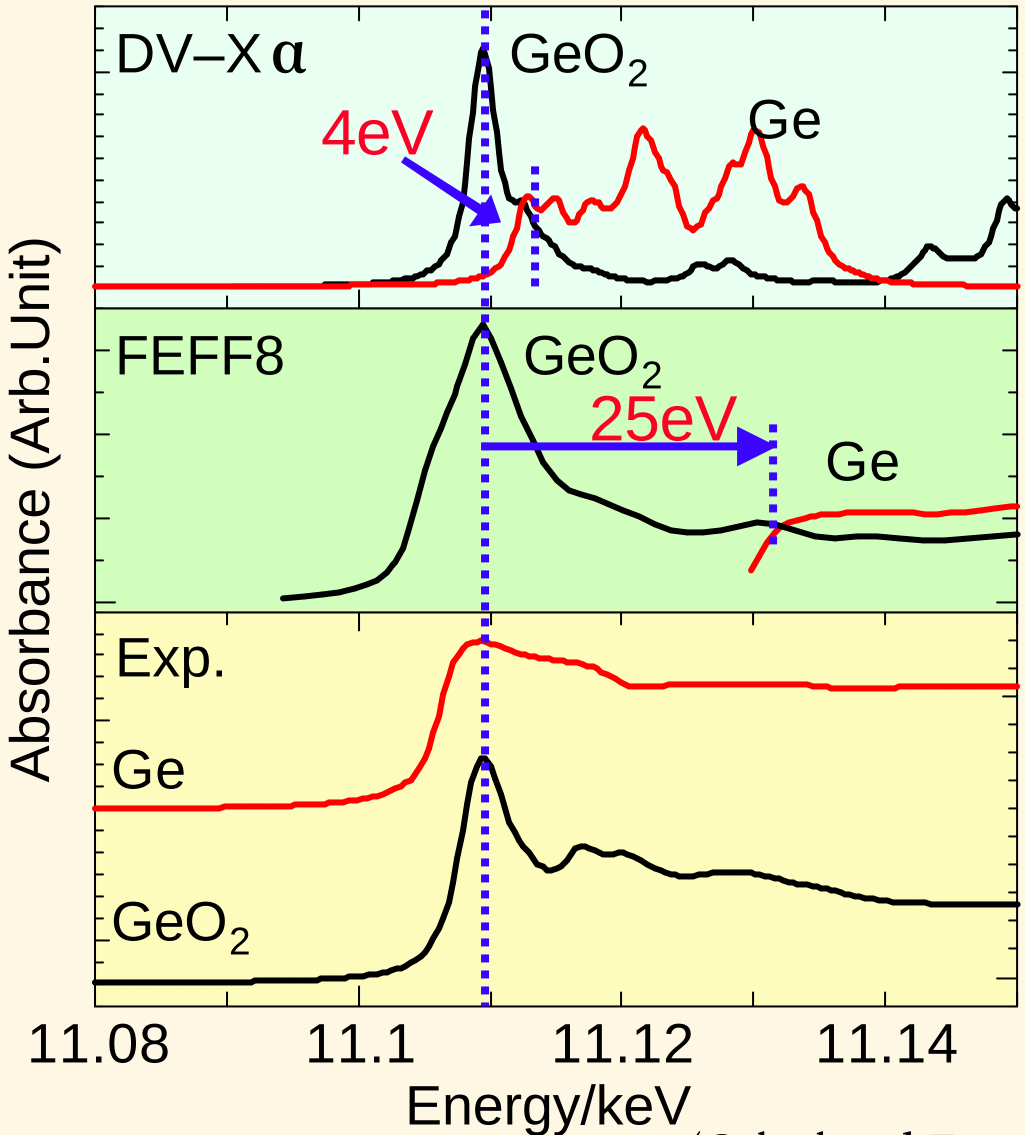
Major Difference between FEFF8 and DV-Xα Methods



	Inter-electron repulsive potential
DV-Xα*	Exact
FEFF8	Approximate (Muffin-Tin)

*Discrete Variational Xα method

Simulation with FEFF8 and DV-Xα method



Relative Energy Difference

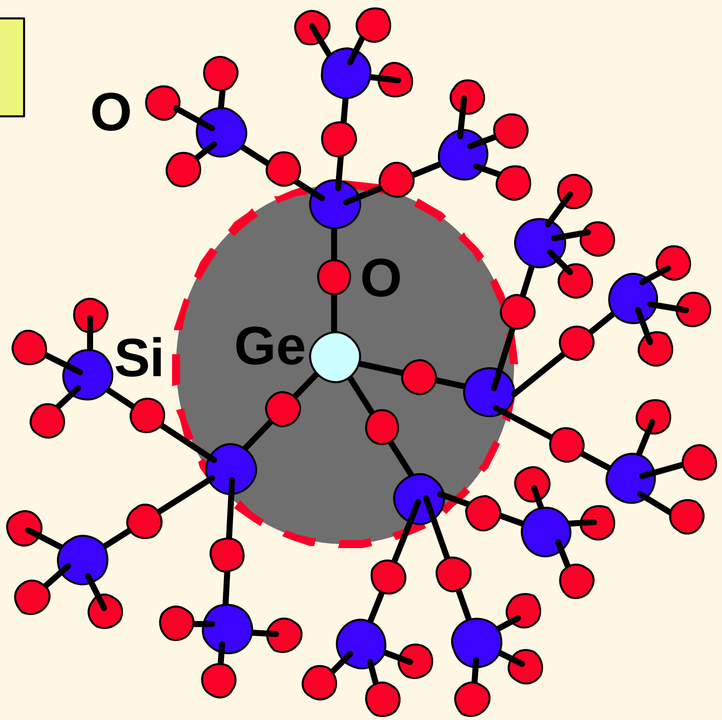
DV-Xα < FEFF8

(Calculated Energy is normalized with GeO_2 peak energy)

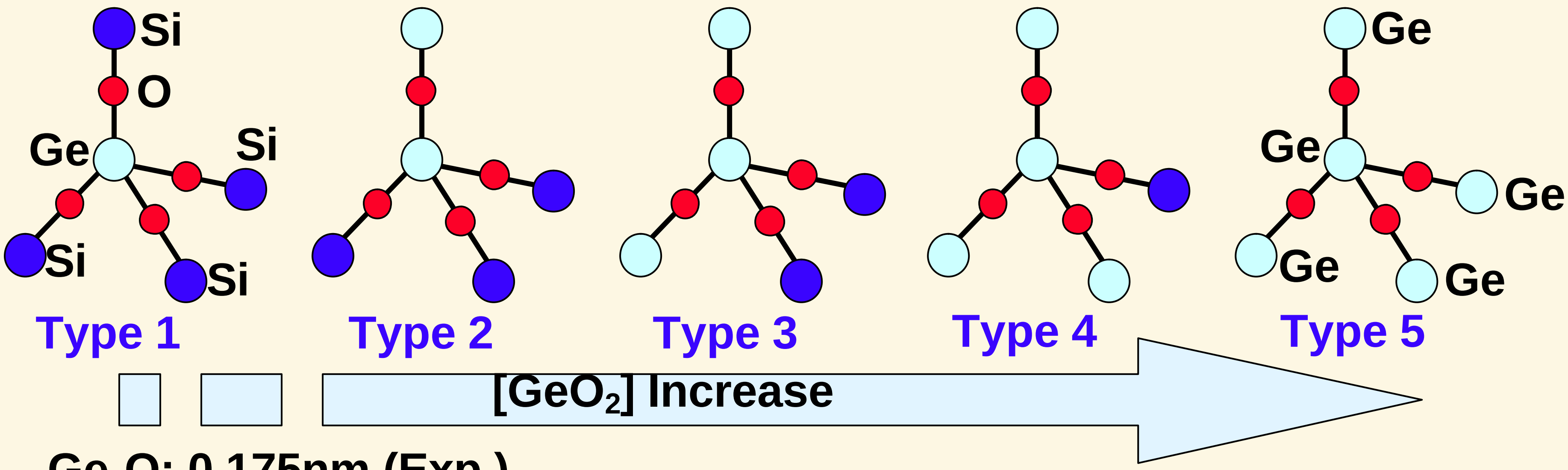
DV-Xα：Three Possible Sources for Peak Shift

1. GeO_2 Clustering
2. Structure Deformation
3. 2nd Nearest-neighbor Vacancy

Calculated Model

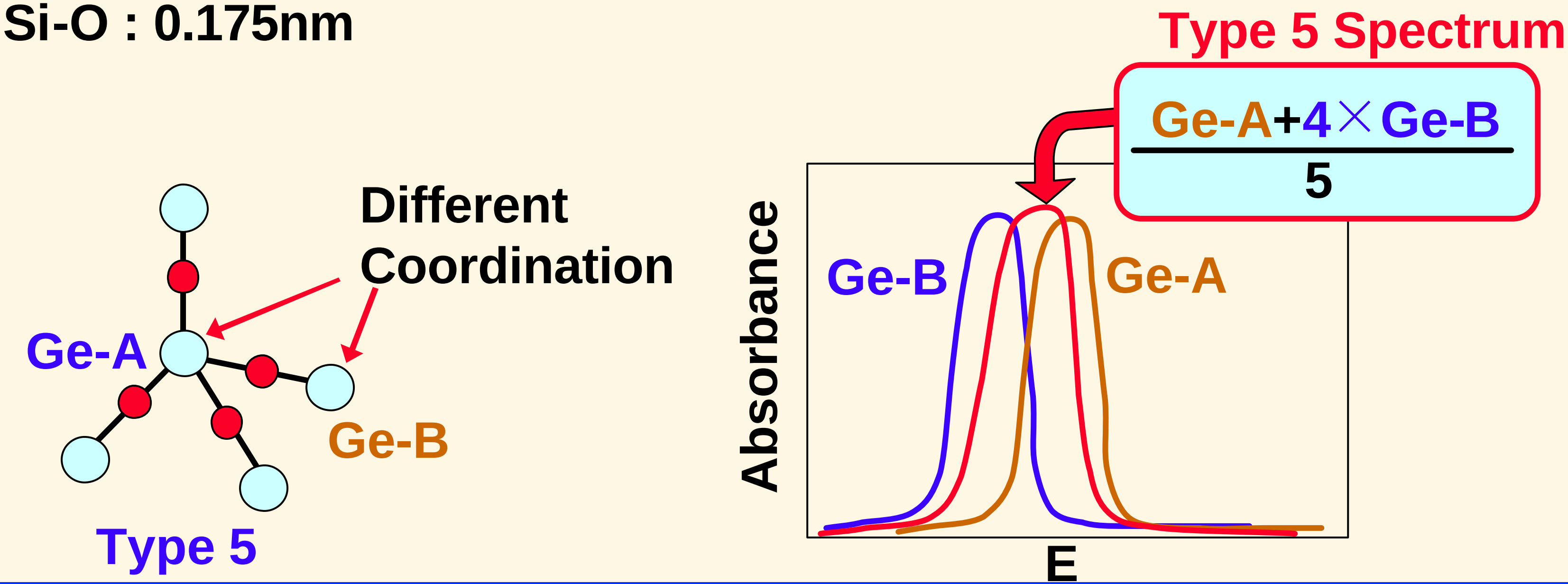


Source 1. GeO_2 Clustering

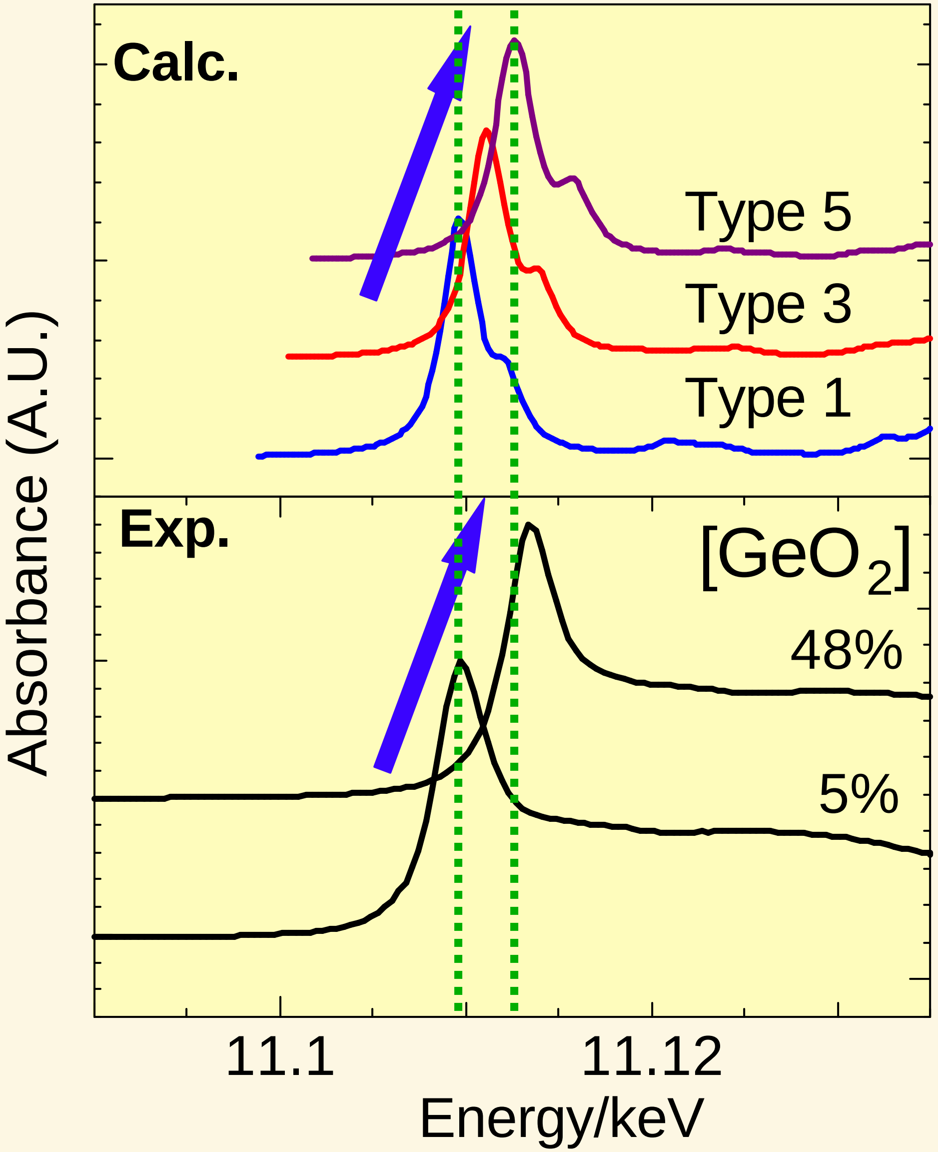


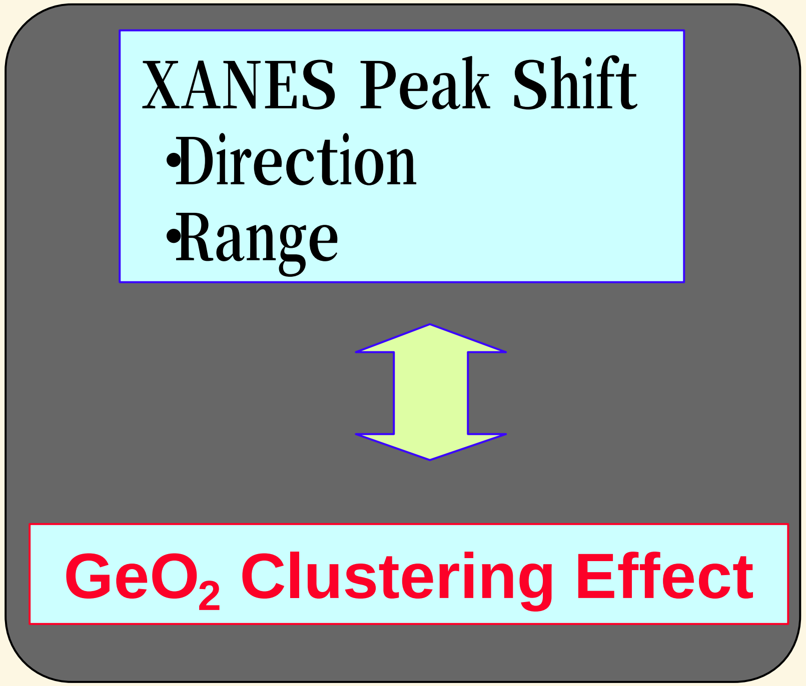
Ge-O: 0.175nm (Exp.)

Si-O : 0.175nm



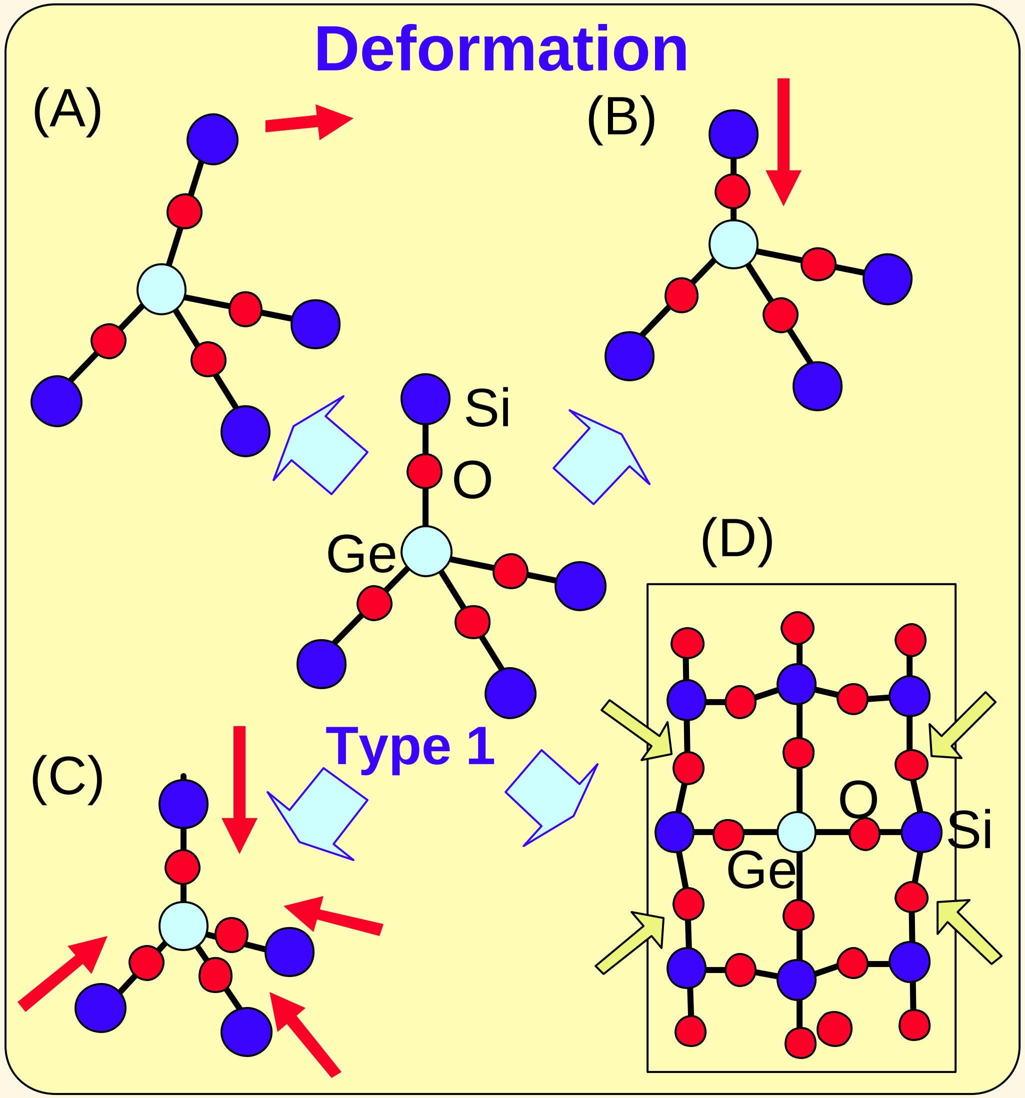
Source 1. GeO_2 Clustering

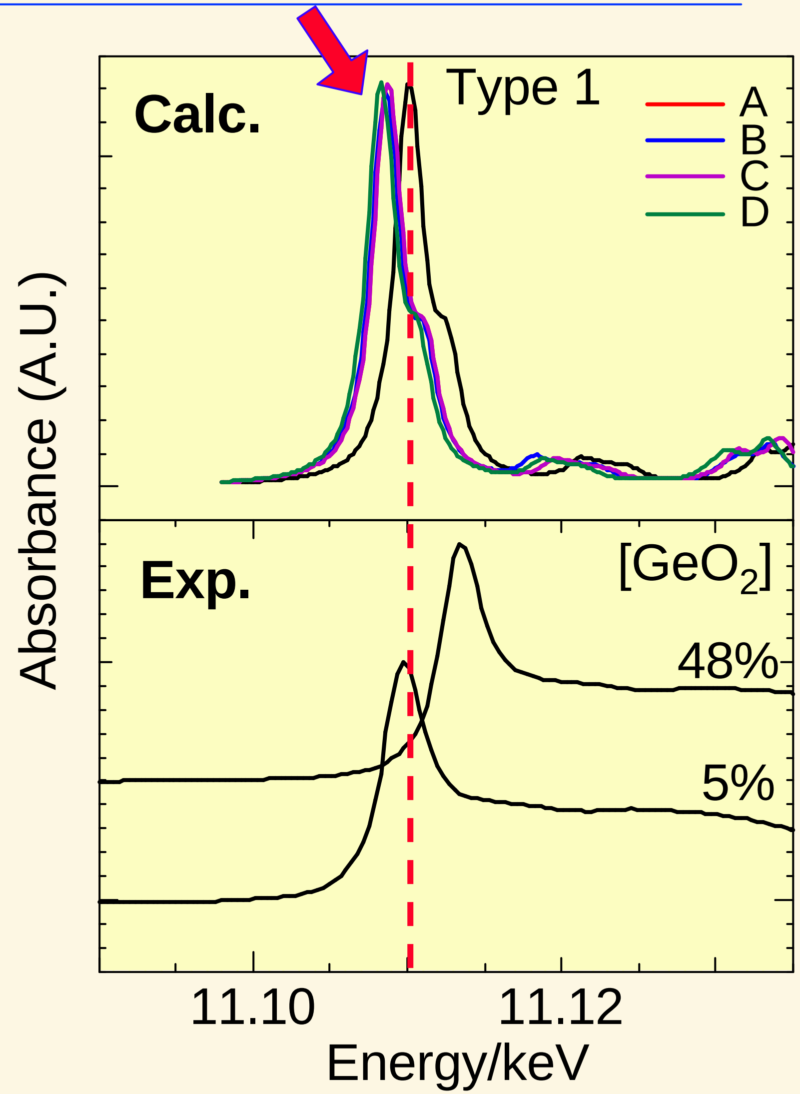




(Calculated Spectrum are normalized with Ge(1) peak energy and $5GeO_2$-SiO_2)

Source 2. Structure Deformation

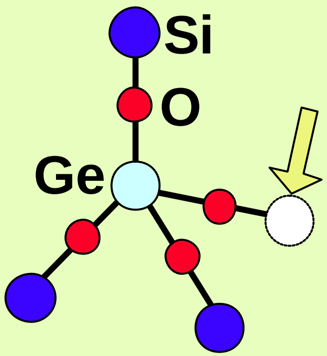




Effect of Deformation is Small

Source 3. 2nd Nearest-neighbor Vacancy

Vacancy



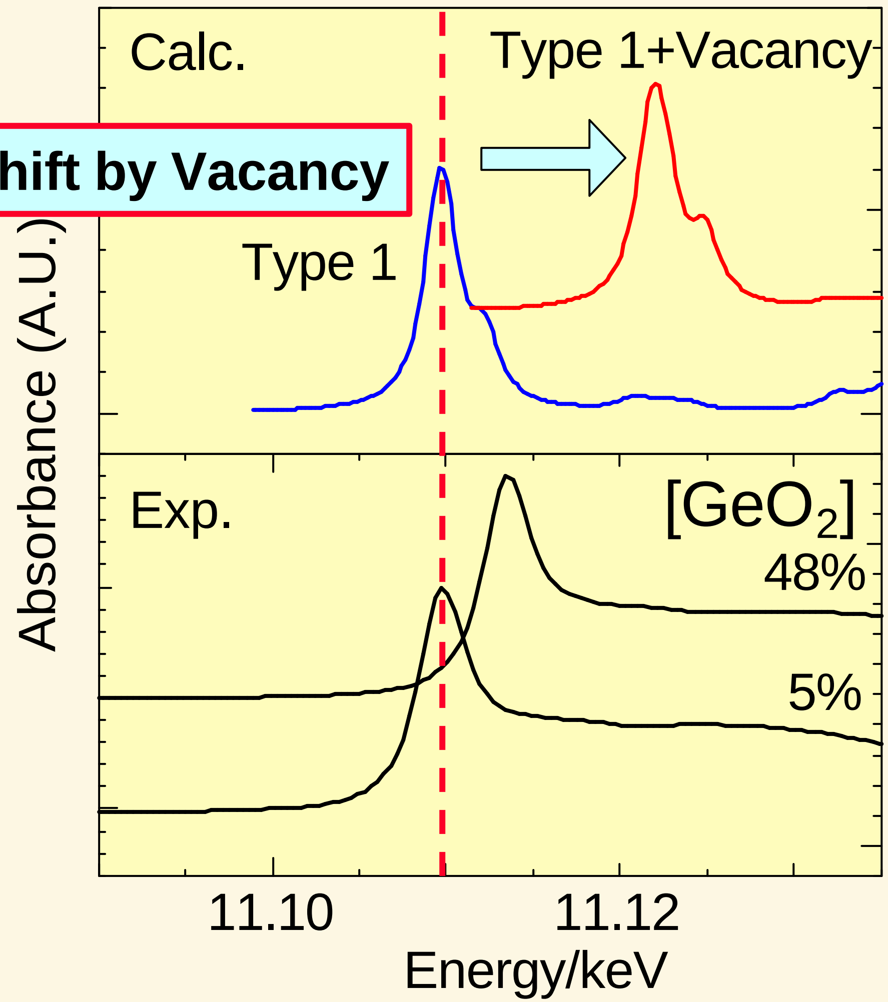
Type 1 + Vacancy

Large Shift

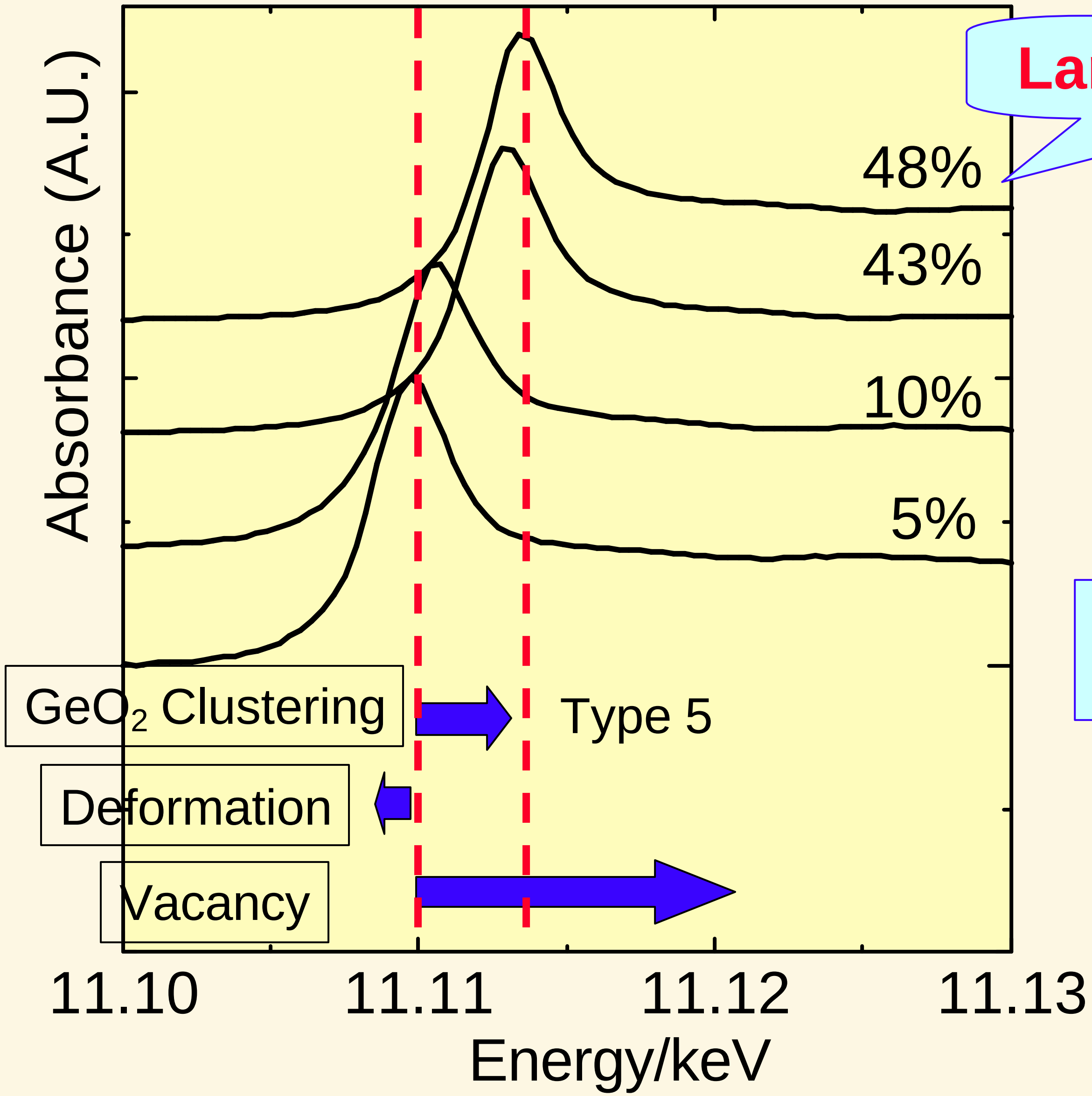
[Vacancy] is very low

Replaced by Impurity Atom

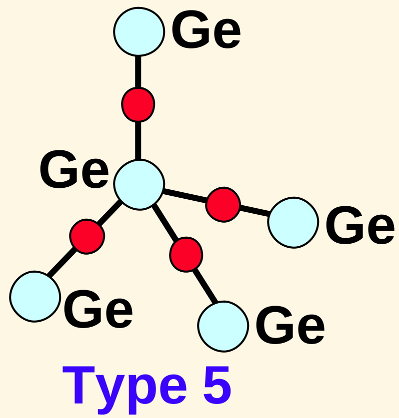
Peak Shift by Vacancy



Discussion



Larger GeO_2 Cluster



Homogeneously Dispersed Small GeO_2 Cluster (Type 1)

Lowering the Loss

Summary

The method for local structural analysis of Ge in GeO_2/SiO_2 glass was developed; XAFS measurements and simulation.

- XANES energy shifts were explained by the GeO_2 clustering effects with DV-Xα simulation.
- High GeO_2 doped SiO_2 glass may have large GeO_2 cluster.

Future Prospect

- XAFS measurements in optical fiber shape specimen to evaluate the relation of its character.
- Local structural analysis of other elements in SiO_2 optical fiber glasses.