Isotopic Fingerprints of 4 and 5-atom Pt containing PL centers in ^{28}Si

M. Steger, A. Yang, T. Sekiguchi, K. Saeedi, M. L. W. Thewalt

Department of Physics, Simon Fraser University, Burnaby, British Columbia, Canada V5A 1S6

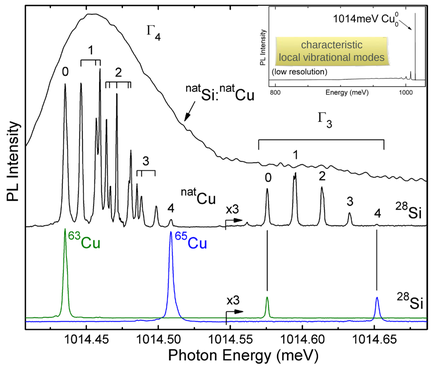
M.O. Henry,[1] K. Johnston,[2] H. Riemann,[3] N. V. Abrosimov,[3] P. Becker,[4] and H.-J. Pohl[5]

[1]School of Physical Sciences, Dublin City University, Dublin 9, Ireland; [2]CERN, ISOLDE, 1211, Geneva, Switzerland

[3]Institute for Crystal Growth (IKZ), 12489 Berlin, Germany; [4]PTB Braunschweig, 38116 Braunschweig, Germany; [5]VITCON Projectconsult GmbH, 07745 Jena, Germany

Isotopic Fingerprints of Deep Centers

- Si Isotope Enrichment: 99.991% ^{28}Si
- [P] ~ 5 x 10^{11} cm^{-3}; [B] ~ 5 x 10^{13} cm^{-3}



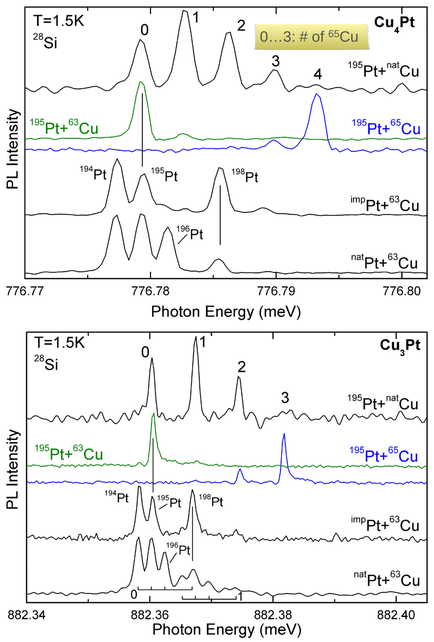
Isotopic fingerprints were first seen for the 1014 meV Cu_0^0 PL line, formerly described as a 2-Cu-atom complex. We demonstrate that at least 4 Cu atoms form this complex by observing five different combinations of the two natural Cu isotopes, ^{63}Cu and ^{65}Cu, through their different exciton binding energies.

This is a novel characterization method for many deep PL centers in Si containing Cu, Ag, Au, Li and Pt.

M. Steger, A. Yang, N. Stavrias, M. L. W. Thewalt, et al., Phys. Rev. Lett. 100, 177402 (2008)
P. Becker et al., Phys. Stat. Sol. A 207, 1, 49 (2010); M. Cardona and M. L. W. Thewalt, RMP 77, 1173 (2005)

The known 777 and 884 meV Pt PL centers

These centers have been proven to be Pt related before.

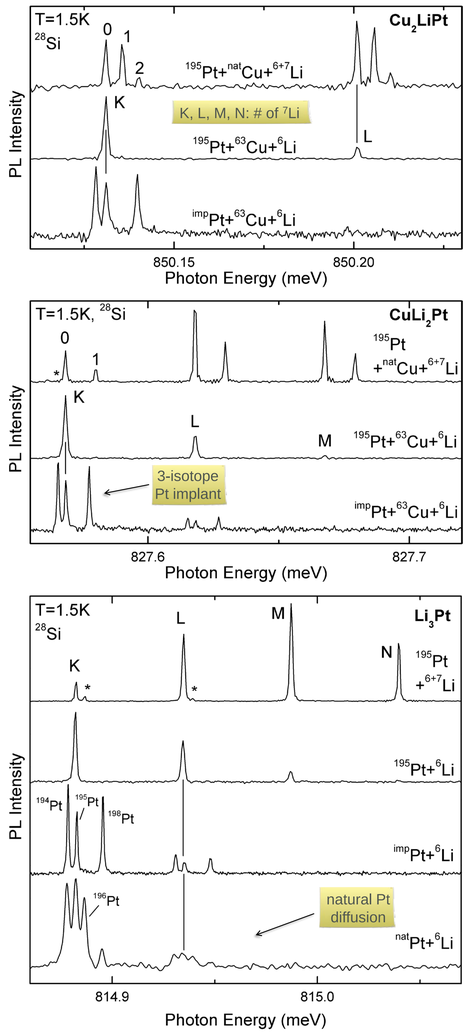


Pt involvement in the 777 and 884 meV PL centers has been detected with a radioisotope method before. Now isotopic fingerprints in ^{28}Si show the presence of a single Pt atom together with 4, respectively 3, Cu atoms in the 777 and 884 meV centers.

M. O. Henry, M. Deicher, R. Magerle, E. McGlynn, A. Stotzler, Hyperfine Interact. 129, 443 (2000)
M. Steger, A. Yang, T. Sekiguchi, K. Saeedi, M. L. W. Thewalt et al., Physica B 404, 5050 (2009)
M. Steger, A. Yang, T. Sekiguchi, K. Saeedi, M. L. W. Thewalt, et al., Phys. Rev. B 81, 235217 (2010)

Isotopic Fingerprints of 4-atom Pt PL centers

Li successively replaces Cu from Cu_3Pt to Li_3Pt



Spectra of the 4-atom $Cu_xLi_{(3-x)}Pt$ series in ^{28}Si.

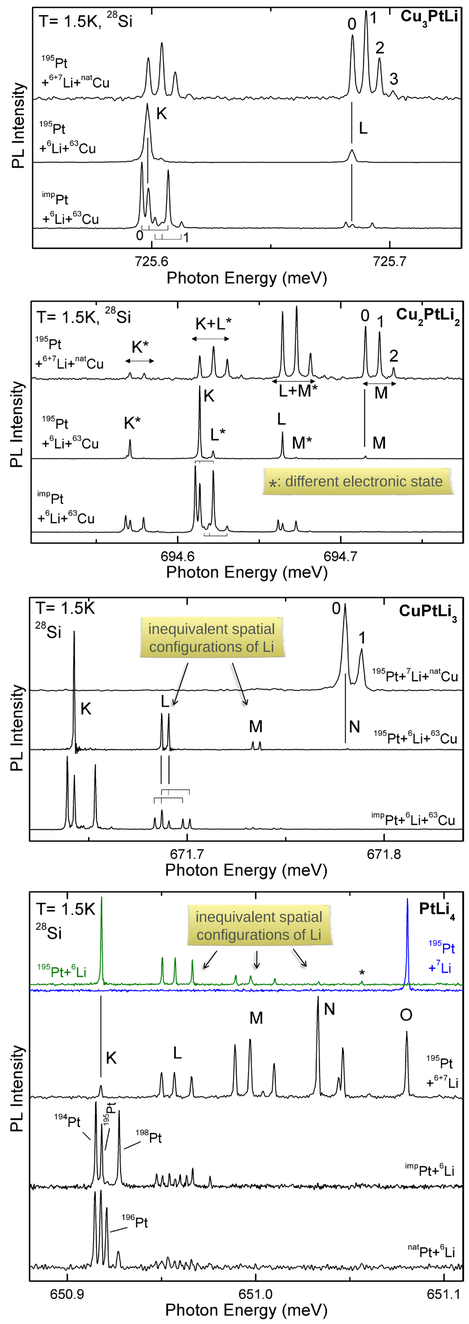
M. Steger, A. Yang, T. Sekiguchi, K. Saeedi, M. L. W. Thewalt et al. *Isotopic fingerprints of Pt containing luminescence centers in highly enriched ^{28}Si*, Phys. Rev. B 81, 235217 (2010)

Analyzing Isotopic Fingerprints

- The number of **Cu** atoms was determined by comparing the relative abundances of the different components 0, 1, 2 and 3 to the now established structure of the Cu_4 center.
- The number of **Li** atoms in each center is determined by varying the ^{6}Li and ^{7}Li isotope content of the samples.
- Our **Pt** containing samples have either only ^{195}Pt (radioactive decay product of ^{195}Hg implants), a simultaneous implant of ^{194}Pt, ^{195}Pt and ^{198}Pt or they have been diffused with natural Pt.
- **Li** has the largest relative change in isotope mass, and highest LVM energy, resulting in the biggest shift of the exciton binding energy per atomic mass unit (amu).
- **Pt** has a very small relative mass change, resulting in a small binding energy shift per amu.

Isotopic Fingerprints of 5-atom Pt PL centers

Li successively replaces Cu from Cu_4Pt to $PtLi_4$

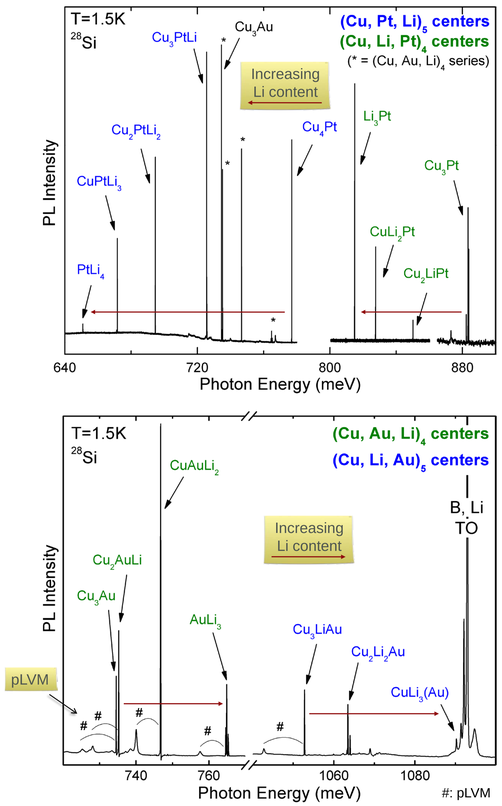


- Spectra of the 5-atom $Cu_xPtLi_{(4-x)}$ series in ^{28}Si.
- Some spectra are obfuscated by overlapping electronic states.
- The split PL lines seen for mixed Li combinations in $CuPtLi_3$ and $PtLi_4$ are likely due to inequivalent spatial configurations of Li isotopes, similar to what has been observed for Cu_4.

M. Steger, A. Yang, T. Sekiguchi, K. Saeedi, M. L. W. Thewalt et al. *Isotopic fingerprints of Pt containing luminescence centers in highly enriched ^{28}Si*, Phys. Rev. B 81, 235217 (2010)

Pt and Au containing complexes

Pt and Au 4- and 5-atom complexes are very similar in that Li is replacing Cu successively.



However, there are major differences.
For Pt centers:
- 5-atom centers have a larger binding energy (lower PL energy) than the 4-atom centers.
- Binding energy increases for Pt centers as Li replaces Cu.

For Au centers:
- 5-atom centers have a smaller binding energy (higher PL energy) than the 4-atom centers.
- Binding energy decreases for Au centers as Li replaces Cu.

M. Steger, A. Yang, T. Sekiguchi, K. Saeedi, M. L. W. Thewalt et al., Physica B 404, 5050 (2009)
M. Steger, A. Yang, T. Sekiguchi, K. Saeedi, M. L. W. Thewalt, et al., Phys. Rev. B 81, 235217 (2010)

Summary

Series	Number of centers
$(Cu, Au, Li)_4$	4
$(Cu, Li, Au)_5$	3
$(Cu, Li, Pt)_4$	4
$(Cu, Pt, Li)_5$	5
$(Cu, Ag)_4$	4
Cu_4Au	1
$(Ag, Au)_4$ (?)	2

- 4 and 5-atom deep metal centers in Si with a family of constituents: Li, Cu, Ag, Pt, Au
- Possibly more constituents.
- **Isotopic fingerprints** in ^{28}Si are a **powerful method** to study isoelectronic bound exciton centers.
- **23** complexes identified.
- **Redefined** the composition of 7.
- Will publish comprehensive data to enable the creation of improved models for these complexes.