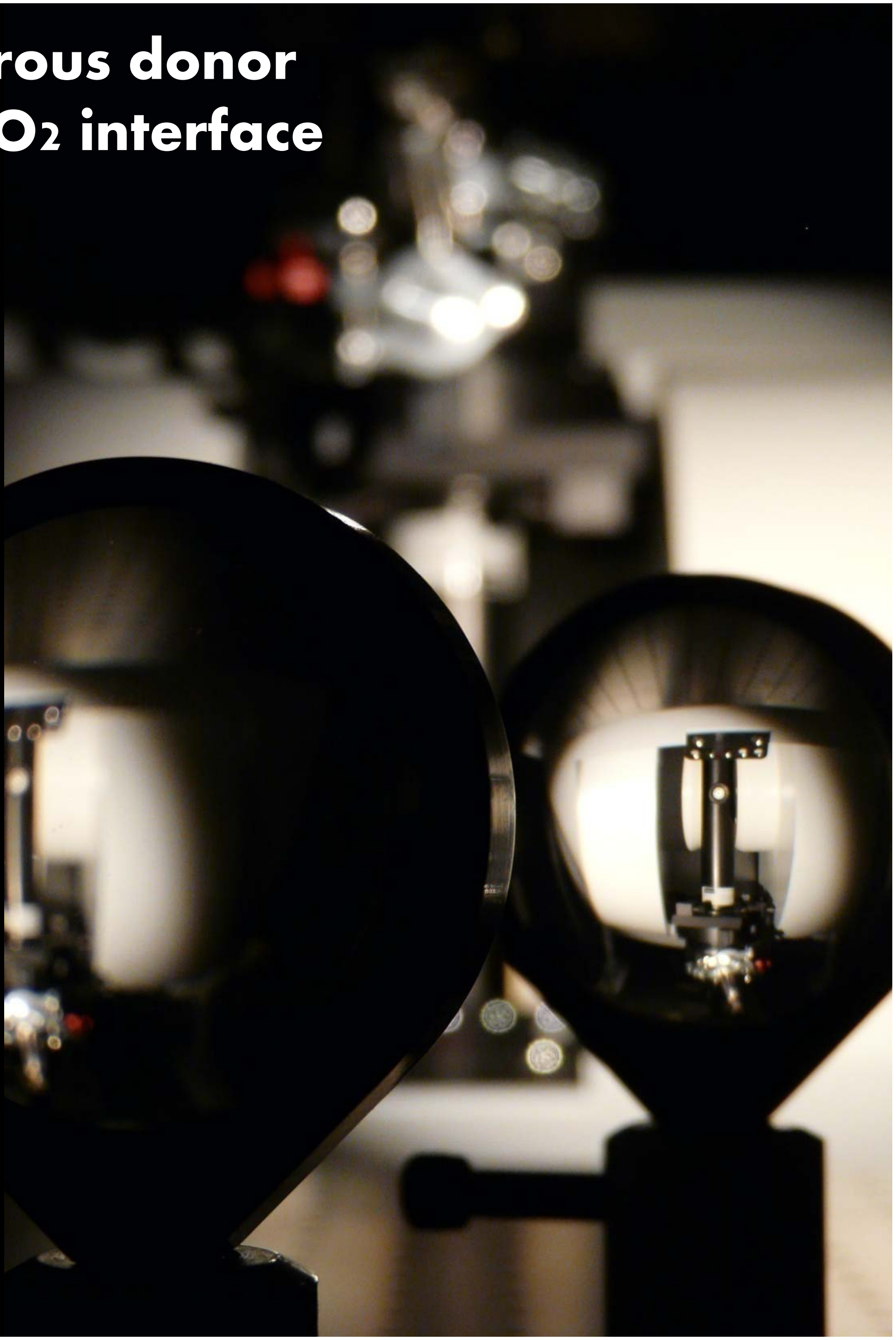
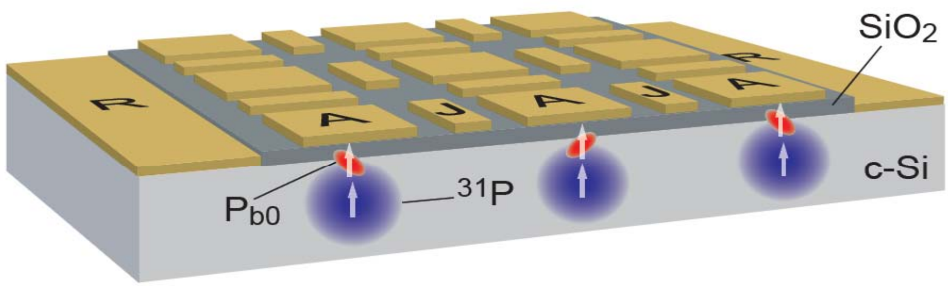
Spin (in)coherence of phosphorous donor electron qubits near the c-Si/SiO_2 interface

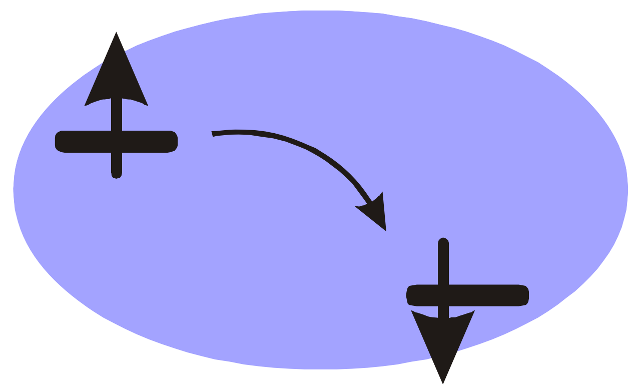


Christoph Boehme
Department of Physics University of Utah

Spin will play an increasingly important role in (silicon based) electronics

Quantum Information Processing





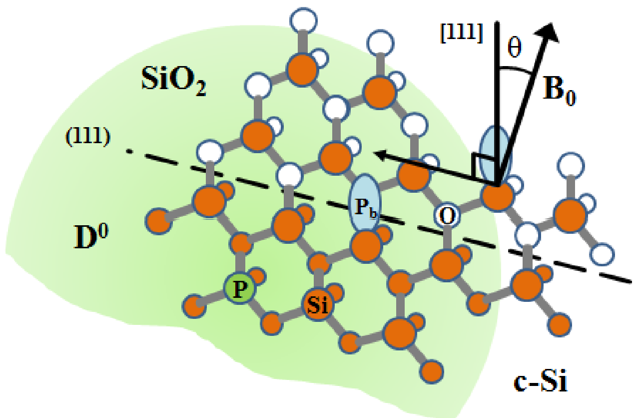
Electron spin T_2 time of ^{31}P donor > 600ms (electron spin) *

*A. M. TYRYSHKIN et al. PHYSICAL REVIEW B 68, 193207 (2003)
* John J. MORTON Alexei M. TYRYSHKIN et al. Nature, vol. 455, 1085 (2008)

How does the readout of ^{31}P qubit work? SPIN – SELECTION RULES!

PHOSPHOROUS SPIN READOUT AT THE SILICONDIOXIDE INTERFACE

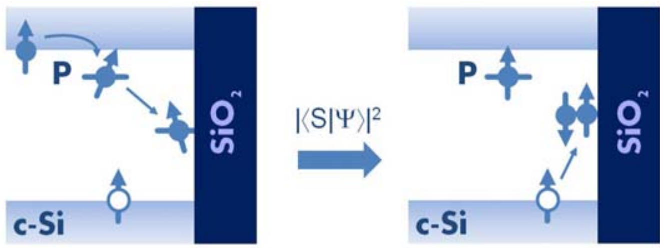
The c-Si (111)/SiO_2 interface



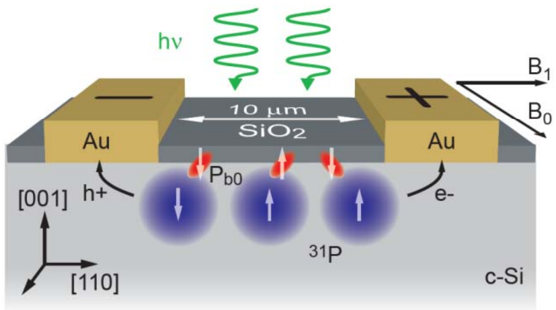
P.M. Lenahan, J. K. Conley, J. Vac. Sci. Technol. B (1998)

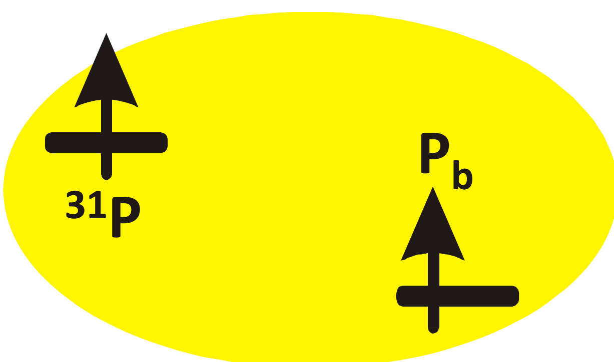
[31]P SPIN READOUT USING SPIN-SELECTION RULES

A. R. Stegner et al. *Nature Physics* (2006)
D. R. McCamey et al. *Appl. Phys. Lett.* (2006)

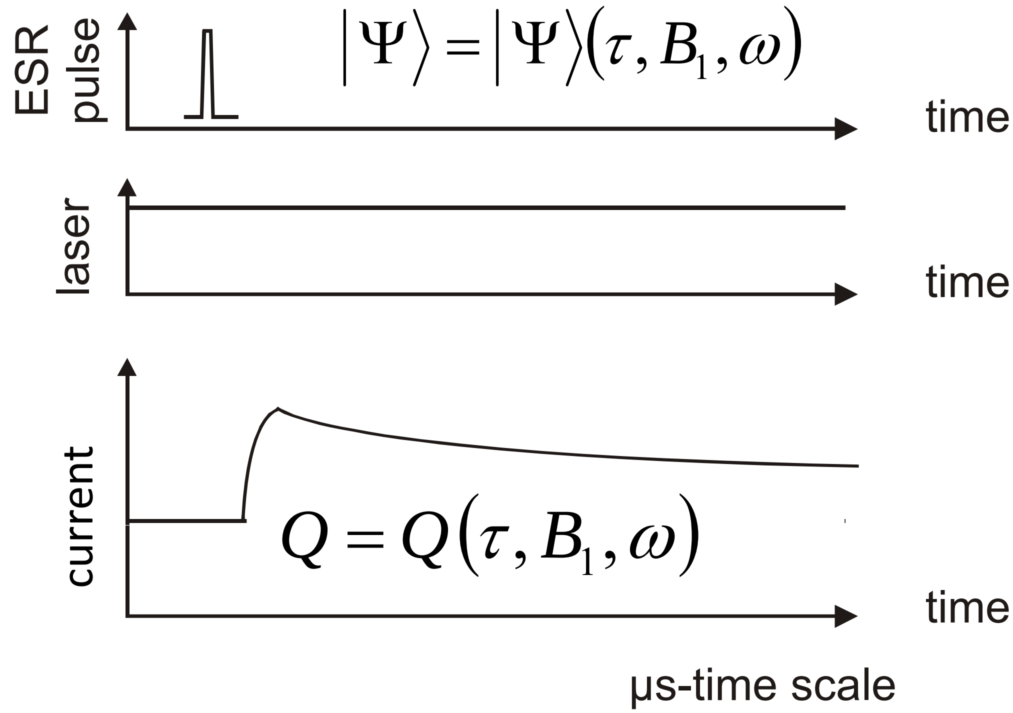


OBSERVATION OF THE PHOSPHOROUS – INTERFACE DEFECT TRANSITION





$$|T_+\rangle \quad |\Psi\rangle$$



$$|\Psi\rangle = |\Psi\rangle(\tau, B_1, \omega)$$

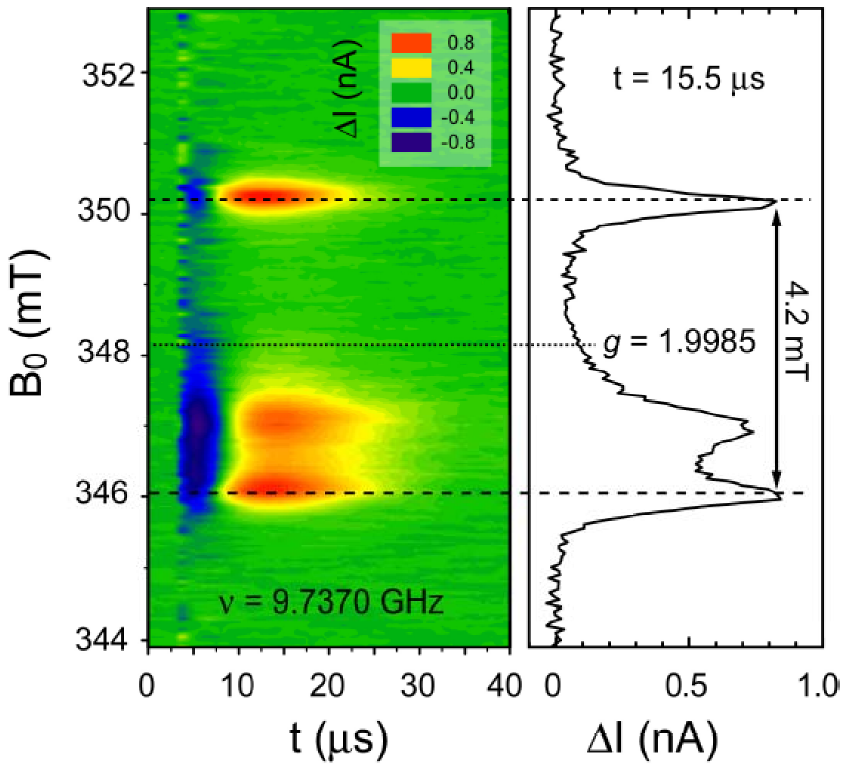
$$Q = Q(\tau, B_1, \omega)$$

$$Q \propto \left|\langle S | \Psi \rangle\right|^2$$

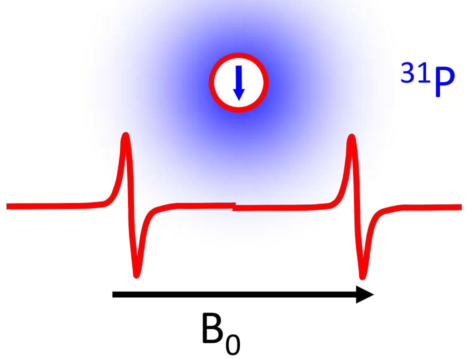
A. R. Stegner, C. Boehme et al. *Nature* Physics 2, 835 (2006).

ELECTRICAL DETECTION OF ^{31}P DONOR STATES

T = 5K



$|\Psi\ (r = 0)|^2 \propto \Delta HFS = 4.2\ mT \propto a^{-3}$



A. R. Stegner, C. Boehme et al. *Nature* Physics 2, 835 (2006).

ELECTRICAL DETECTION OF ^{31}P DONOR STATES

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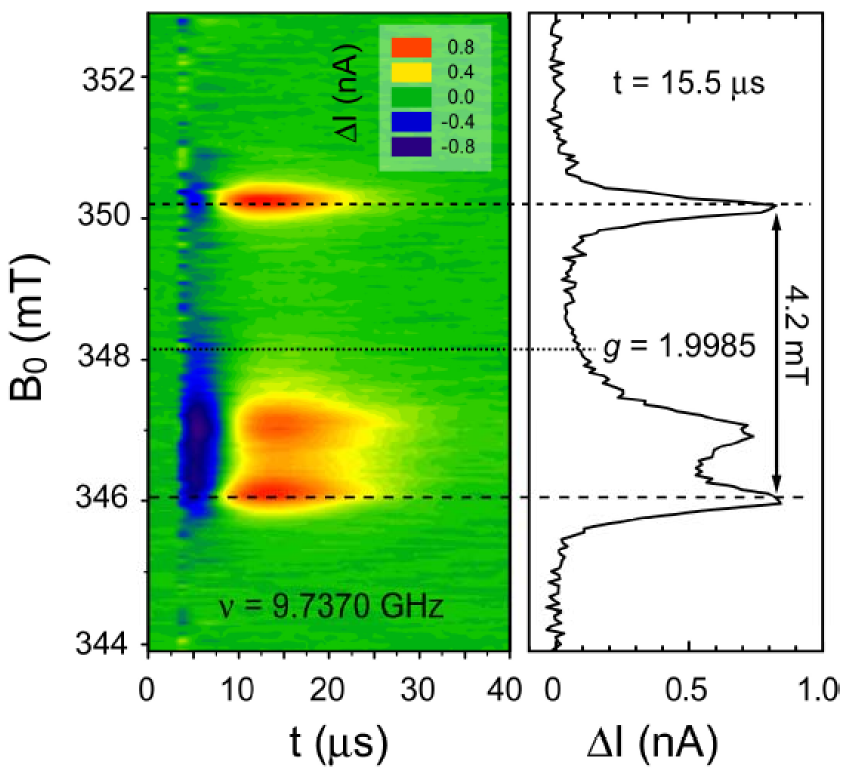
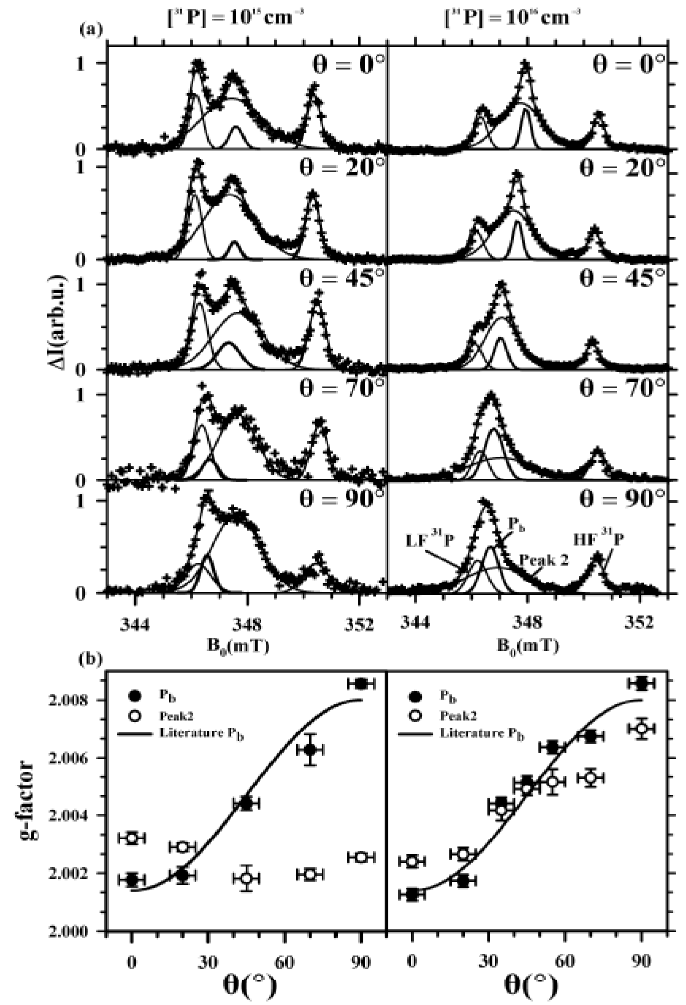


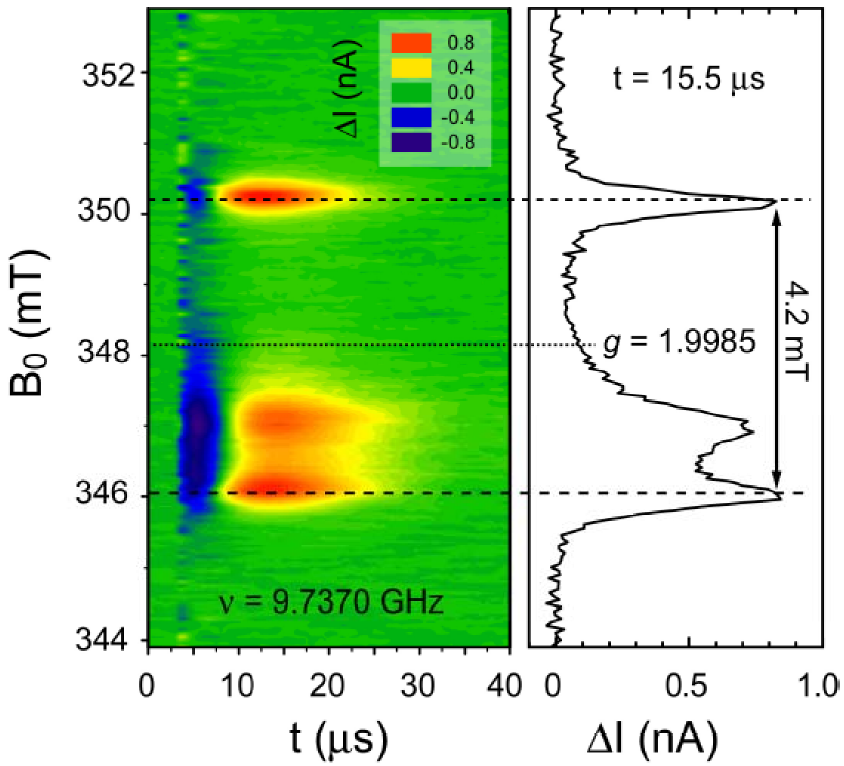


Seoyoung Paik et al.arXiv:0905.0416v1 (2009)

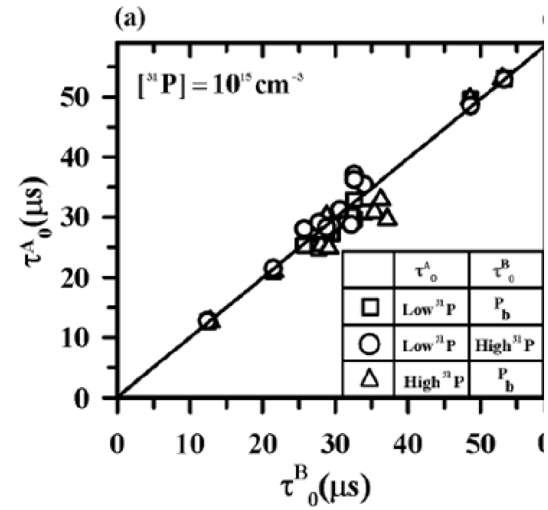
A. R. Stegner, C. Boehme et al. *Nature* Physics 2, 835 (2006).

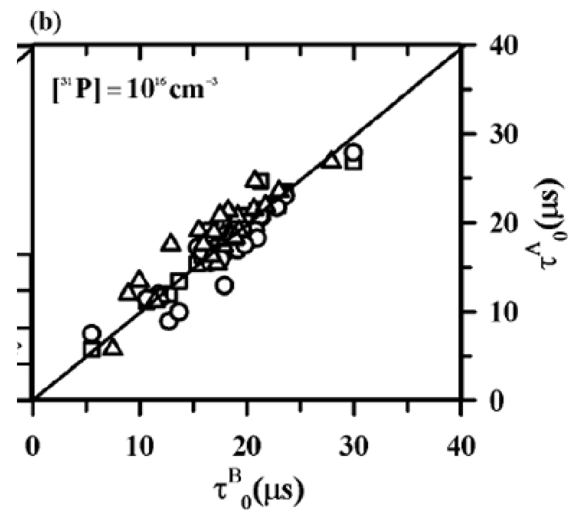
ELECTRICAL DETECTION OF ^{31}P DONOR STATES

T = 5K



$$Q \propto \left|\langle S|\Psi\rangle\right|^2 \ ?$$



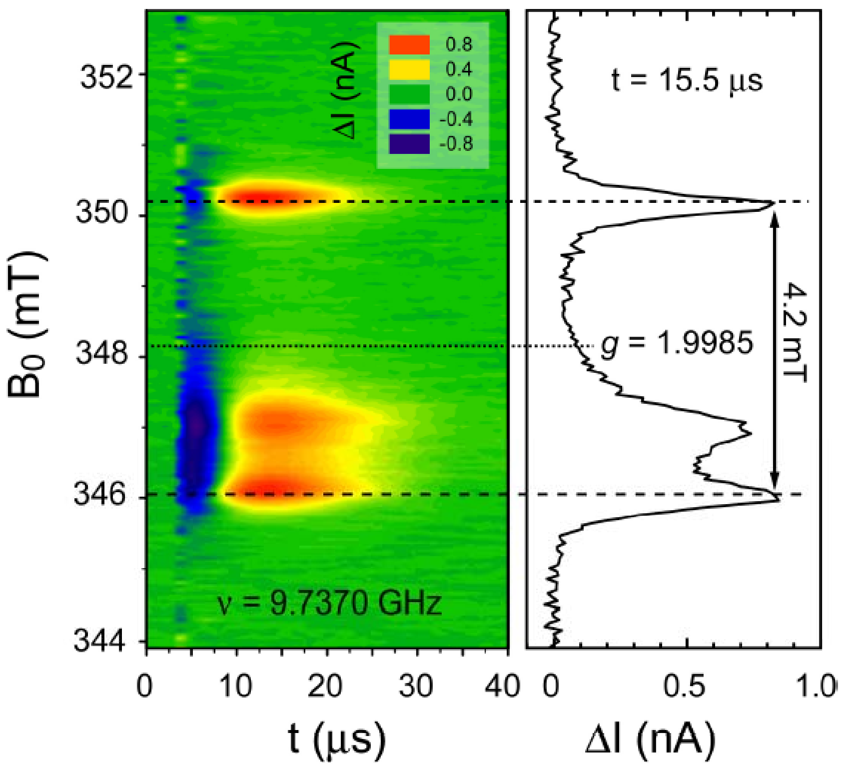


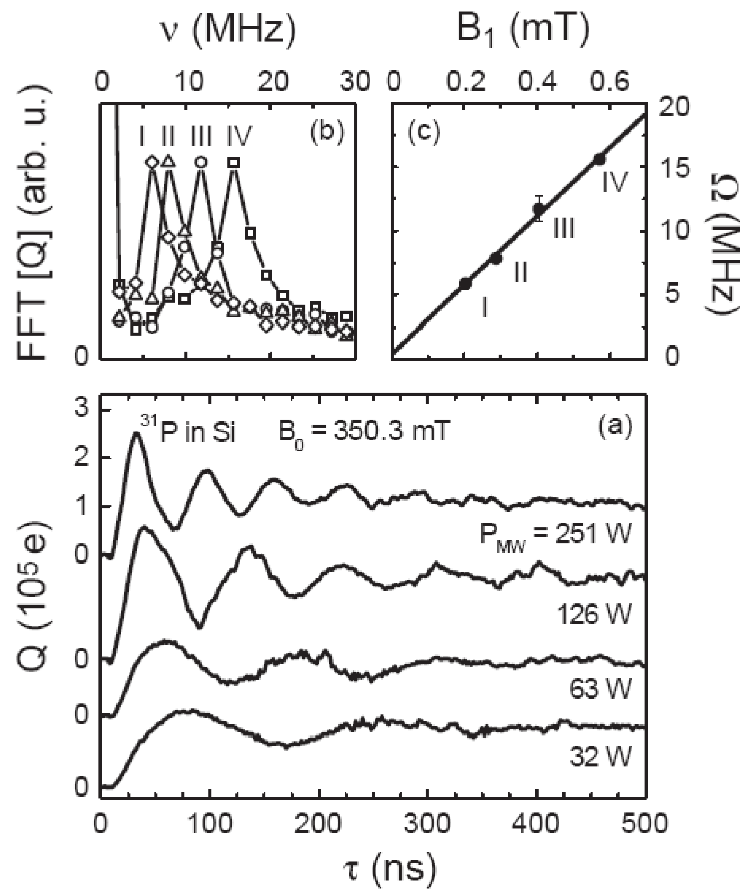
Seoyoung Paik et al.arXiv:0905.0416v1 (2009)

A. R. Stegner, C. Boehme et al. *Nature* Physics 2, 835 (2006).

ELECTRICAL DETECTION OF ^{31}P DONOR STATES

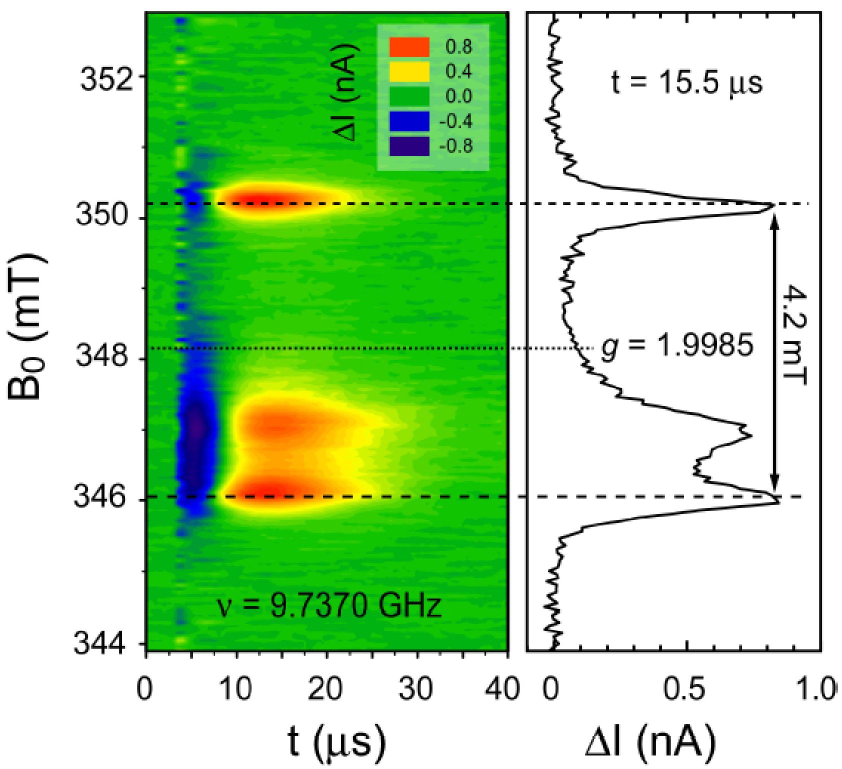
T = 5K

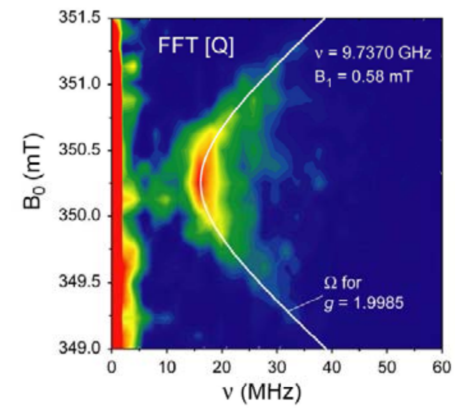


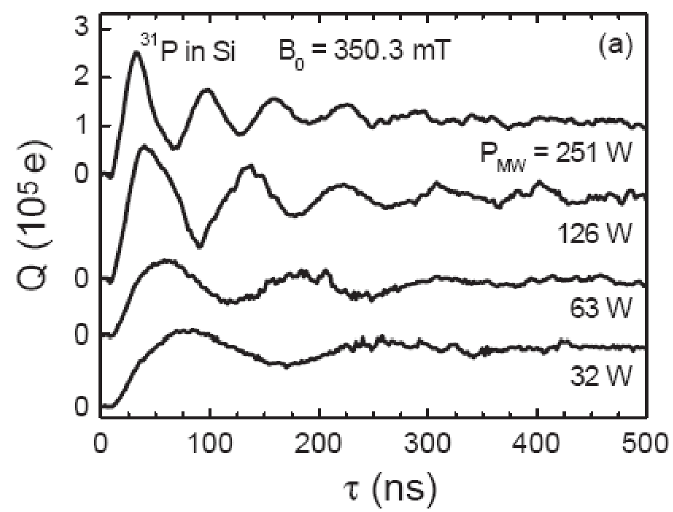


ELECTRICAL DETECTION OF ^{31}P DONOR STATES

T = 5K

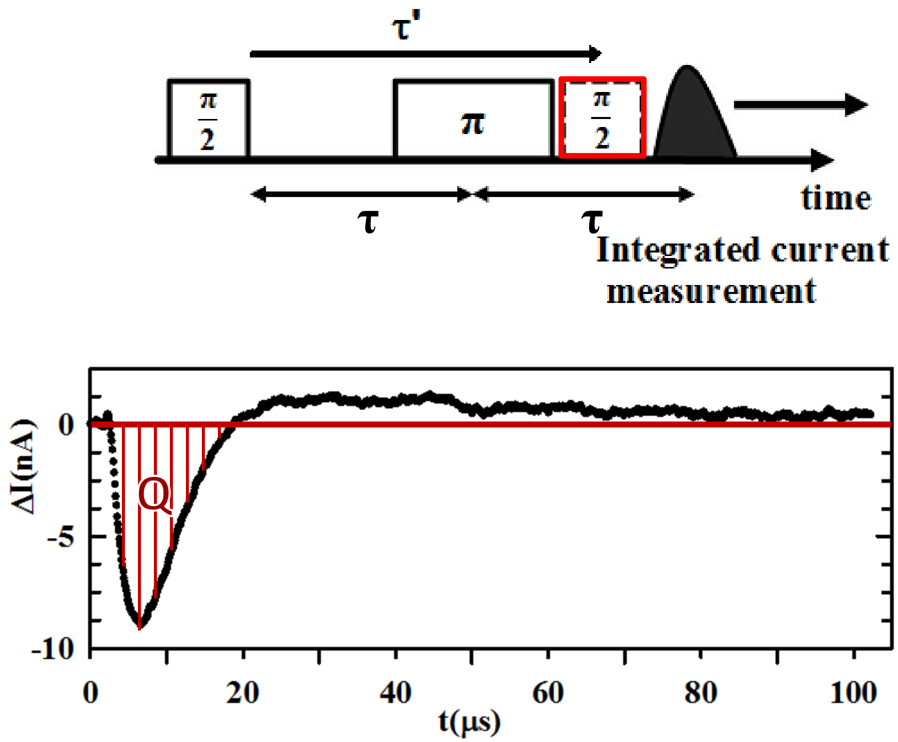






Weakly coupled ^{31}P-P_b spin pairs

ELECTRICALLY DETECTED HAHN-ECHOES OF NEAR INTERFACE ^{31}P

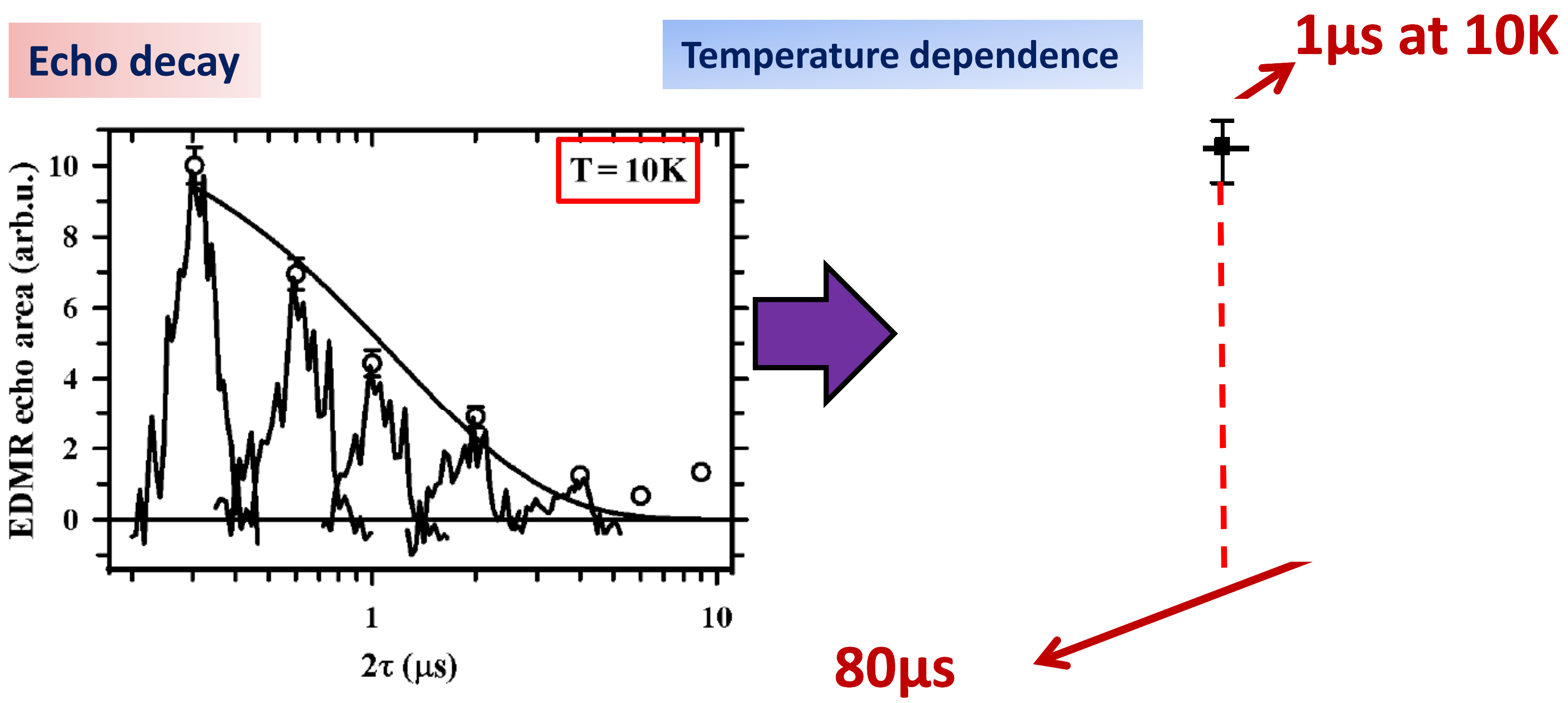


Increase dephasing time τ → Echo intensity decays → Decay time : T_2 coherence time

ELECTRICALLY MEASURED T2 RELAXATION

Echo decay

Temperature dependence



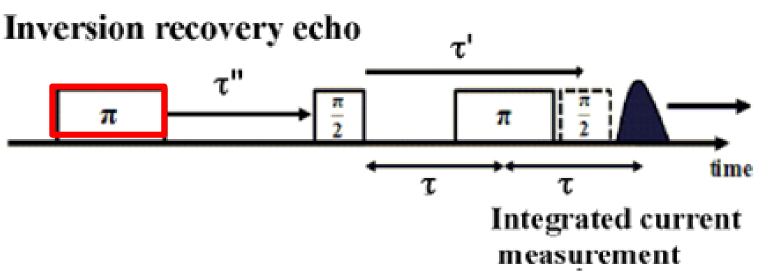
- T_2 time at interface is const. at different temperatures.
- ESR T_2 has temperature dependence : T_1 limits T_2 in the ESR measurement.*
- T_2 time at interface is much shorter than in bulk T_2 at low temperature.

* A. M. Tyryshkin et al. PHYSICAL REVIEW B **68, 193207 (2003)**

ELECTRICALLY DETECTED INVERSION RECOVERY EXPERIMENT

IS SPIN RELAXATION TIME TRULY LIMITED BY ELECTRONIC TRANSITION OR IS FIELD FLUCTUATIONS AT INTERFACE ?

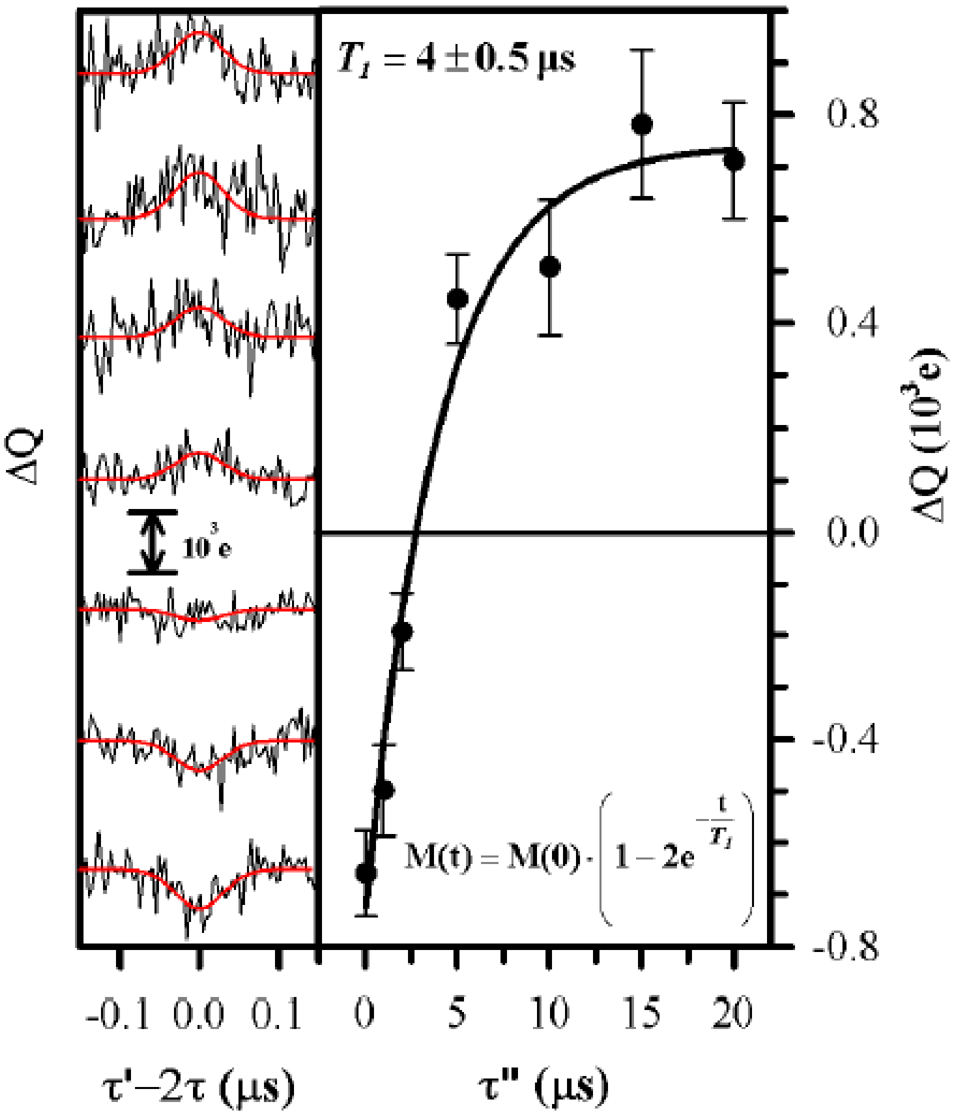
R. de Sousa,
Phys. Rev. B 76, 245306 (2007).



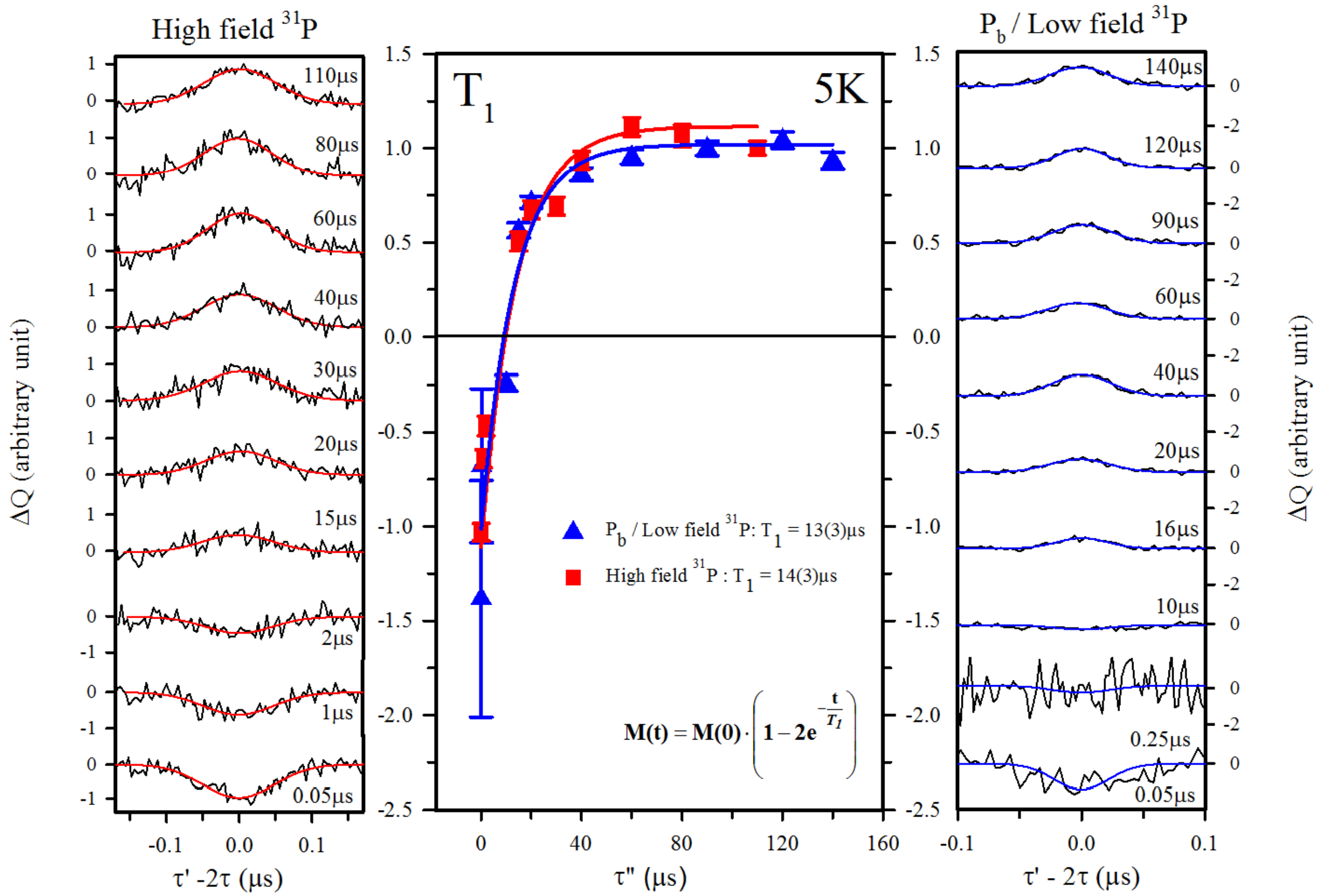
$T_1 = 4.0(5)\mu s$

$T_2 = 1.3(8)\mu s$ **at low HF -^{31}P peak**

$T_2 = 2.1(7)\mu s$ **at high HF -^{31}P peak**



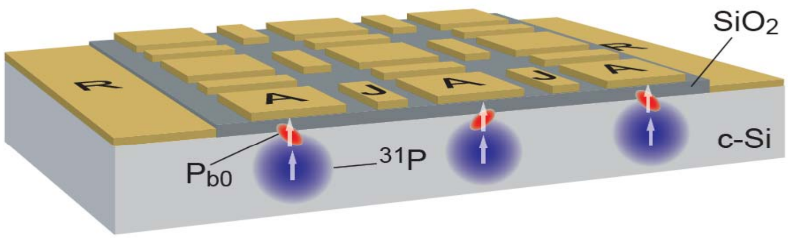
ELECTRICALLY T1 RELAXATION AT LOWER INTERFACE STATE DENSITIES



c-Si/SiO2 INTERFACE WITH 4 TIMES SMALLER INTERFACE DENSITY

S. –Y. Paik, S.-Y. Lee, D. R. McCamey, C. Boehme, *arXiv: 0905.0416* (2009).

RELAXATION TIMES OF NEAR INTERFACE PHOSPHOROUS DONOR STATES



T = 5K	High field ^{31}P	Low field ^{31}P / P_b
EDMR T_1	14(3)μs	13(3)μs
EDMR T_2	4.0(5)μs	1.0(2)μs

CONCLUSIONS

- EDMR T_1, T_2 times are much shorter than ESR T_2 time.
- electronic transition time probably limits T_1 relaxation time.
- Incoherence time T_2 of ^{31}P qubit is shortened due to the interface states.

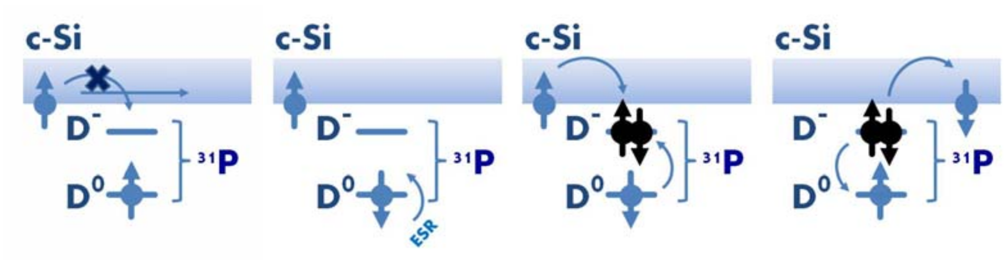
Silicon-based QCs using ^{31}P qubits (AND READOUT) need to overcome the limitation imposed by interface defects

S. –Y. Paik, S.-Y. Lee, D. R. McCamey, C. Boehme, *arXiv: 0905.0416* (2009).

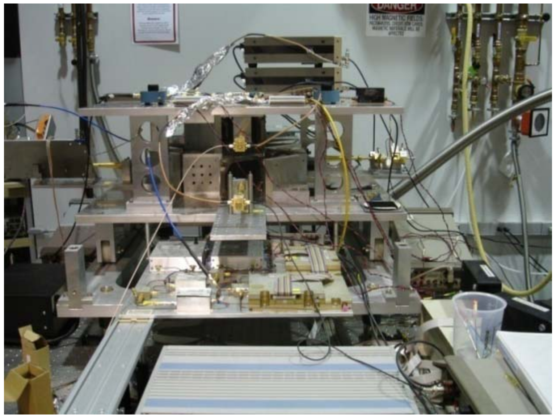
SPIN-DEPENDENT TRAPPING AT BULK PHOSPHOROUS IN SILICON

- **SPIN TRAPPING**

  - D. D. Thornton, A. Honig, *Phys. Rev. Lett.* (1973)



Quasi-optical
Superheterodyne EPR System



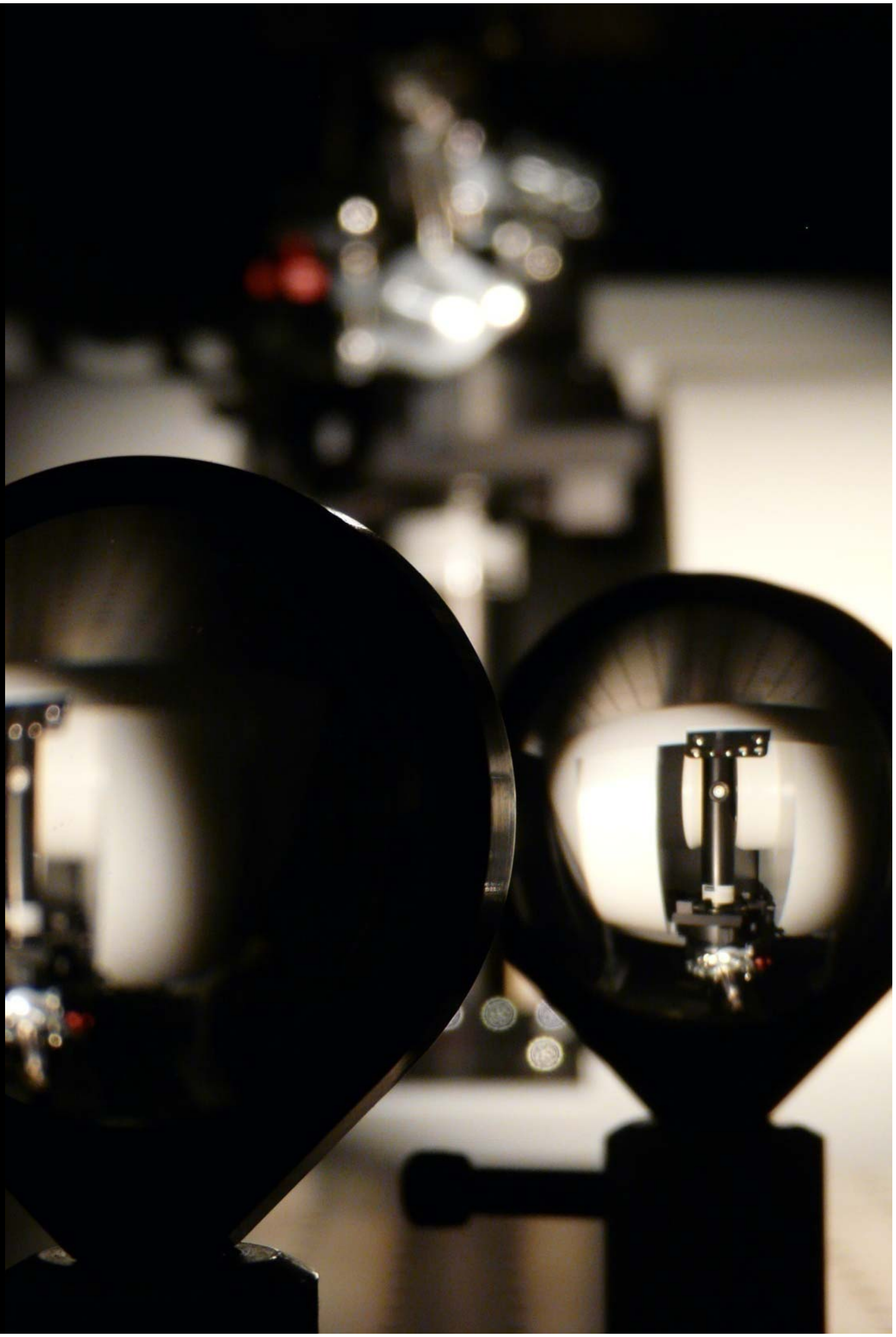
J. van Tol *et al.*, *Rev. Sci. Instrum.* **76,** 074101 (2005).

SPIN-TRAPPING IS ONLY VISIBLE WHEN ELECTRONS ARE STRONGLY POLARIZED – AT VERY HIGH MAGNETIC FIELDS

SEE GAVIN MORLEYs TALK THAT WILL COME NEXT

G. W. Morley, D. R. McCamey, H. A. Seipel, L. C. Brunel, J. van Tol & C. Boehme. *Phys. Rev. Lett.* 101, 207602 (2008).

Questions?



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