Dynamical Decoupling of Nitrogen-Vacancy Electron Spins in Diamond and Nanodiamond

Defense of the Bachelor thesis
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26.02.2017

Contents

Motivation

- magnetic field imaging: idea of single spins as sensors on the nanoscale
- quantum system used for this purpose ideally meets these criteria:
  - stable
  - controllable
  - can be easily prepared and read out

Motivation

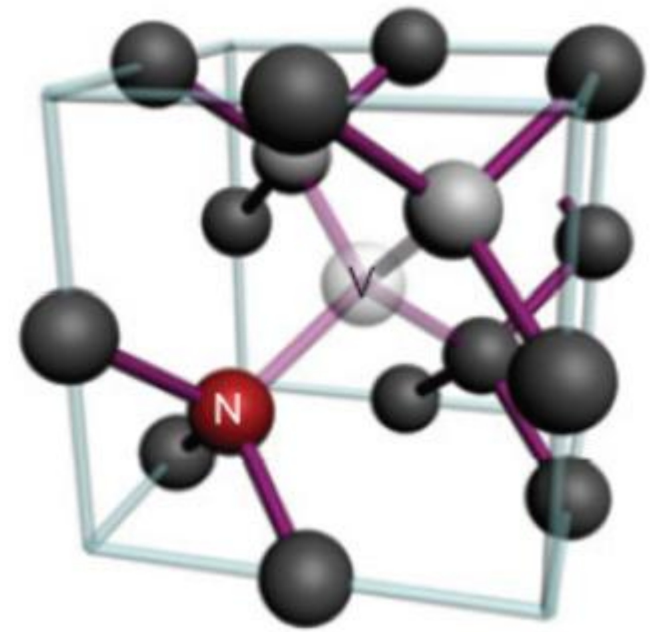
- NV center meets these conditions
- High sensitivity requires long coherence times

→ NV spin has to be decoupled from unwanted interactions with the environment

→ **Dynamical decoupling techniques**

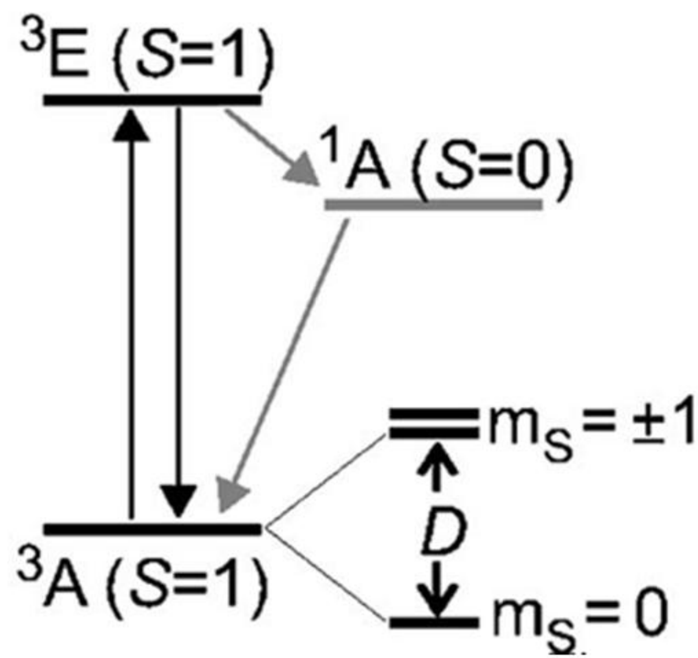
NV center

- Vacancy (V) next to substitu-tional nitrogen (N) atom in diamond lattice
- optically stable
- long coherence times even at room temperature
- single photon fluorescence



NV center

- description with 3 level system
- GS m_S=0 and m_S=±1 separated by D=2.87 GHz
- relaxation ES→GS: luminescence with ZPL at 637nm
- highest fluorescence at m_S=0
- optical initialization
- NV Hamiltonian:



$$H = DS_z^2 + g\mu_B\vec{S}\vec{B} + A_{\parallel}S_zI_z + A_{\perp}(S_xI_x + S_yI_y) + H_E$$

Rabi oscillations

- single electronic spin (2 level system) in B-field
  → Zeeman splitting:

$$\hat{H}_Z = -\gamma_S \hat{S}\hat{B} = -\frac{\gamma_S \hbar B_z}{2}\hat{\sigma}_z = \frac{\hbar}{2}\omega_B \hat{\sigma}_z$$

- adding oscillating field

$$\hat{B} = B_1(\hat{x}\cos\omega t - \hat{y}\sin\omega t)$$

$$\rightarrow \quad \hat{H}_B = -\gamma\frac{\hbar}{2}\left(B_1(\cos\omega t\hat{\sigma}_x - \sin\omega t\hat{\sigma}_y)\right)$$

Theory

Rabi oscillations

- total Hamiltonian:

$$\hat{H} = \frac{\hbar}{2}\begin{pmatrix} \omega_B & -\omega_1 e^{i\omega t} \\ -\omega_1 e^{-i\omega t} & -\omega_B \end{pmatrix}$$

- for $\omega_1 \ll \omega_B$, perturbation theory yields:

$$\boxed{P_{1\to 0}(t) = \frac{\omega_1^2}{(\omega-\omega_{10})^2+\omega_1^2}\sin^2\left(\frac{\sqrt{(\omega-\omega_{10})^2+\omega_1^2}}{2}t\right)}$$

Rabi's formula

- in resonance: $\omega=\omega_{10} \rightarrow$ $P_{1\to 0}(t)=\sin^2\left(\frac{\omega_1 t}{2}\right)$

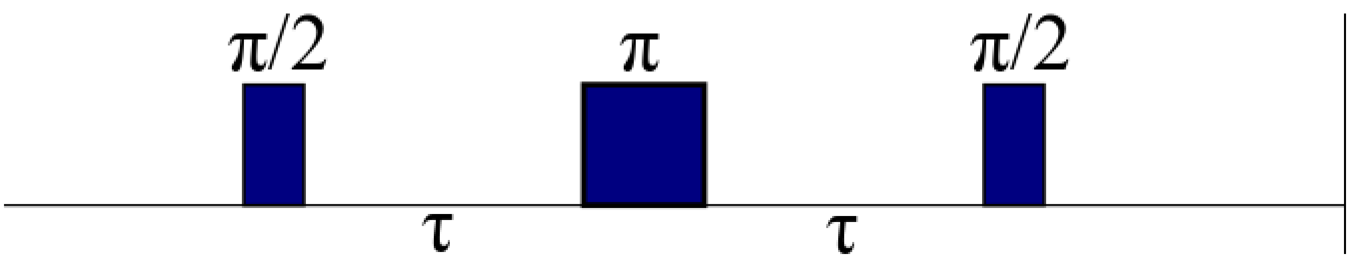
Bloch sphere

Image of rotations on bloch sphere

Theory

Dynamical Decoupling sequences

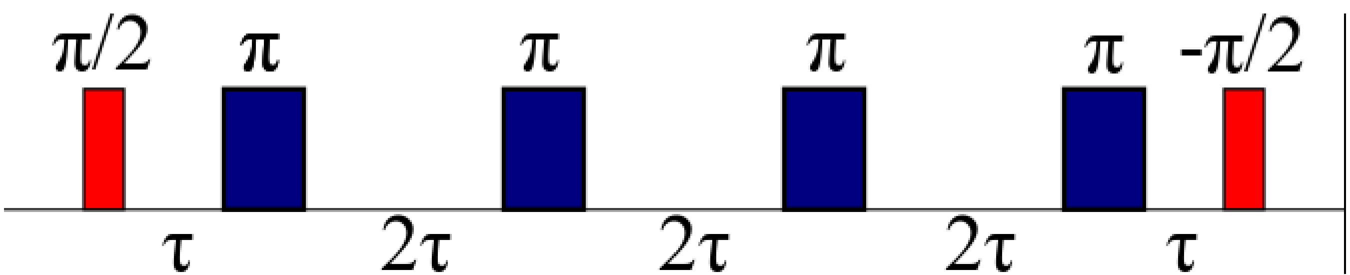
- Hahn Echo
  - 1st spin echo experiment
  - Measurement of T_2



Theory

Dynamical Decoupling sequences

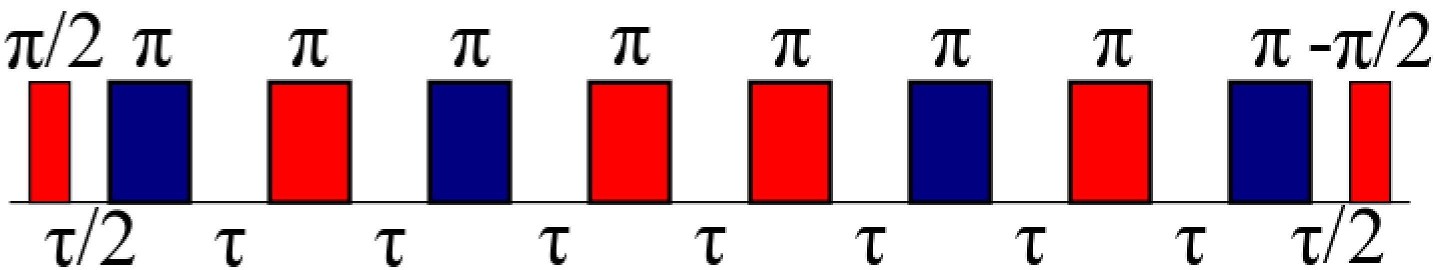
- CPMG
  - multiple π rotations around single axis
  - higher decoupling efficiency than Hahn Echo



Theory

Dynamical Decoupling sequences

- XY
  - CPMG pulse spacing
  - π rotations around 2 axes → 3D decoupling



Spectral decomposition

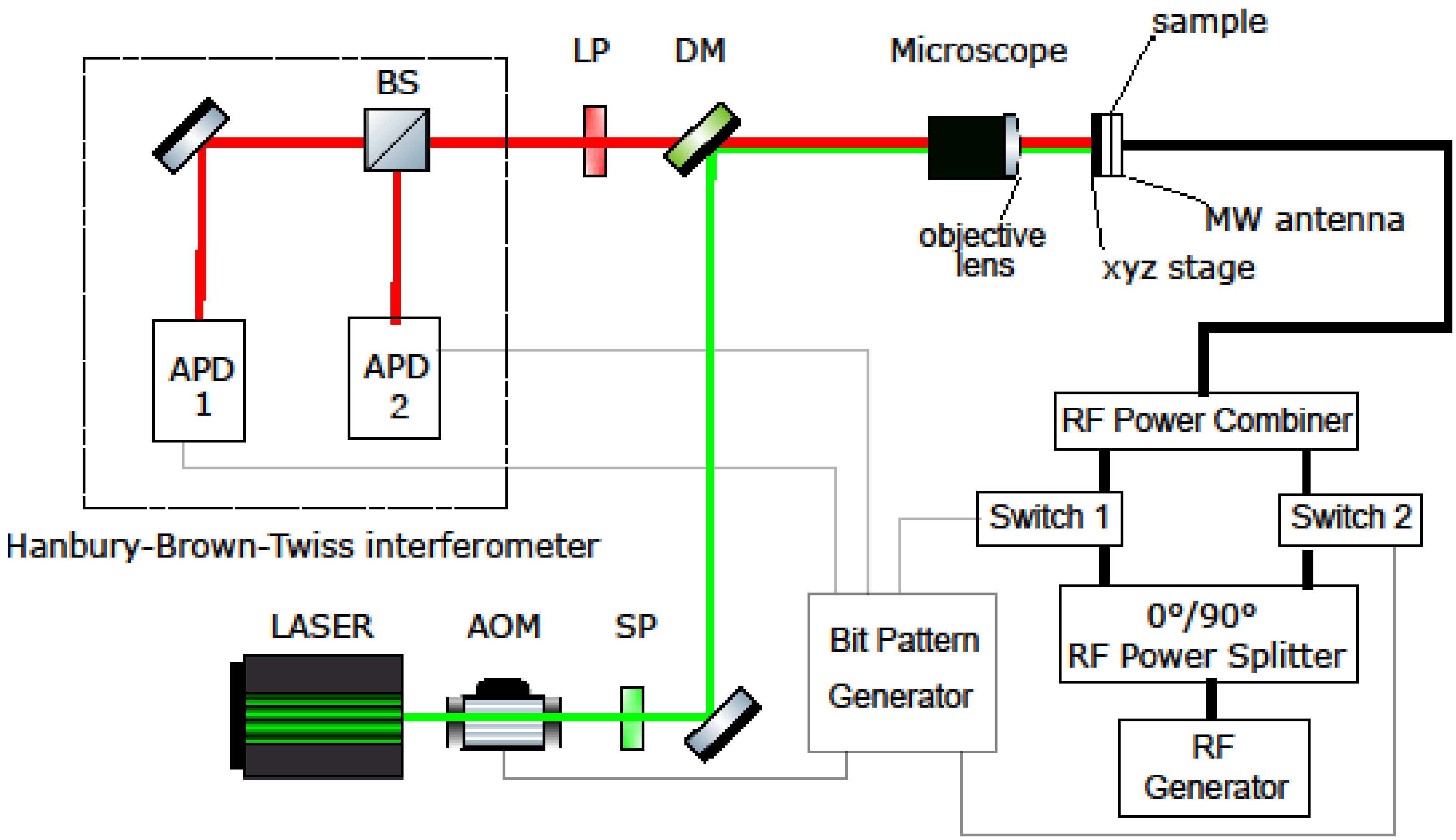
- In general: loss of coherence obeys $C(t)=e^{-X(t)}$ with

$$\chi(t) = \frac{1}{\pi}\int_0^\infty d\omega S(\omega)\frac{F(\omega t)}{\omega^2}$$

S(ω): spectral density function

F(ωt): filter function

Setup



sample
LP
DM
Microscope
BS
objective lens
MW antenna
xyz stage
APD 1
APD 2
RF Power Combiner
Switch 1
Switch 2
Hanbury-Brown-Twiss interferometer
LASER
AOM
SP
Bit Pattern Generator
0°/90° RF Power Splitter
RF Generator

Measurements

Conclusion and Outlook

- successful implementation of DD protocols
- CPMG: improvement of factor 50 in nanodiamond and 200 in bulk → 60 µs
- CPMG outperforms XY
- Spectral density in good agreement with other experiments
- error sources: BPG (pulse errors), MW splitter, AOM
- future
  - better time and phase control
  - Implementation of other decoupling protocols