Contents

Abstract i

Zusammenfassung iii

Contents v

1 Introduction 1
- 1.1 Anomalous dynamics . . . 1
- 1.2 Critical dynamics at phase transitions . . . 4
- 1.3 The dissipative central spin model . . . 7
- 1.4 Outline of this thesis . . . 9

2 The *quantum dot central spin model* 13
- 2.1 Semiconductor quantum dots . . . 13
- 2.2 The central electron spin . . . 15
  - 2.2.1 Electron Zeeman interaction . . . 15
  - 2.2.2 Continuous wave laser excitation . . . 16
  - 2.2.3 Periodic pulsed laser excitation . . . 19
  - 2.2.4 Dissipation by spontaneous emission . . . 23
  - 2.2.5 Electron master equation in the absence of nuclear spins . . . 24
- 2.3 The nuclear environment . . . 26
  - 2.3.1 Nuclear Zeeman interaction . . . 26
  - 2.3.2 Dipolar interactions . . . 27
  - 2.3.3 Quadrupolar interactions . . . 27
  - 2.3.4 Collective nuclear spin states . . . 28
- 2.4 The electron–nuclei interactions . . . 31
  - 2.4.1 Hyperfine interaction . . . 32
  - 2.4.2 Non–collinear interaction . . . 38
- 2.5 Coupled dynamics in the quantum dot spin system . . . 39
  - 2.5.1 Electron spin decoherence . . . 39
  - 2.5.2 Dynamic nuclear polarization . . . 43
  - 2.5.3 Summary of electron–nuclei feedback discussed in this thesis 45

3 Nuclear spin cooling using Overhauser field selective coherent population trapping 49
- 3.1 Motivation . . . 49
- 3.2 Driven–dissipative electron–nuclei system . . . 51
- 3.3 Description of the coupled electron–nuclei dynamics . . . 53
  - 3.3.1 Derivations . . . 53
  - 3.3.2 Qualitative description of the coupled dynamics . . . 59

Issler, Mena Elisabeth 1988- (DE-588)1084611384
Anomalous and critical dynamics in a dissipative ...
2015

digitalisiert durch
IDS Basel/Bern, im Auftrag der
Schweizerischen Nationalbibliothek

3.4 Nuclear spin cooling and spectroscopic signatures 60
3.4.1 Homogeneous hyperfine coupling 60
3.4.2 Inhomogeneous hyperfine coupling 63
3.4.3 Suppression of T_2 decoherence 66
3.4.4 Spectrum and density of states of the generalized Overhauser field 66
3.4.5 Generalization to multiple nuclear spin species 72
3.4.6 Nuclear spin decoherence 74
3.5 Anomalous nuclear spin diffusion 74
3.6 Conclusion 79

4 Real–time monitoring of Lévy flights in a single quantum system 81
4.1 Introduction 81
4.2 System 82
4.3 Periodic optical excitation of the electron 84
4.3.1 Derivations 85
4.4 Coupled electron–nuclei dynamics 92
4.4.1 Schrieffer–Wolff transformation 93
4.5 Lévy flights in the nuclear environment 97
4.6 Real–time monitoring of the Lévy flights 99
4.7 Limitations of the scheme 100
4.7.1 Modified trapping time distribution 101
4.7.2 Physical origin of the limitations 102
4.7.3 Electron dephasing 103
4.7.4 Imperfect laser polarization 104
4.7.5 Intrinsic limitation 106
4.7.6 Displaced echo sequence 106
4.8 Conclusion and outlook 109

5 Signatures of a dissipative phase transition controlled by a single quantum system 111
5.1 Introduction 111
5.2 System 112
5.3 Master equation for the spin environment 114
5.3.1 Adiabatic elimination of the excited central system state . . 114
5.3.2 Adiabatic elimination of environmental spin coherences . . . 116
5.3.3 Tracing over the degrees of freedom of the central spin . . . 117
5.4 Signatures of criticality 118
5.4.1 Realization in quantum dots 119
5.4.2 Phase characterization by dynamic nuclear polarization . . . 119
5.4.3 Continuous change in the dynamic nuclear polarization . . . 120
5.4.4 Evolution of the nuclear distribution 121
5.4.5 Multiple nuclear species 122
5.4.6 Spectral gap 126
5.4.7 Thermodynamic limit 127
5.4.8 Constant hyperfine coupling 130
5.5 Conclusion and outlook 130

6 Conclusion and outlook 133

List of figures 147

Curriculum vitae 152

Acknowledgments 155