Preface

Diluted magnetic semiconductors, or semimagnetic semiconductors, seemed for a while to be one of those research topics whose glory (i.e., the period of most extensive research) belonged already to the past. This particularly applied to "traditional" diluted magnetic semiconductors, i.e., substitutional alloys of either II–VI or IV–VI semiconductors with transition metal ions. Fortunately, a discovery, in the beginning of the nineties [1, 2], of ferromagnetic ordering in III–V DMSs with critical temperatures reaching $\sim$170 K has renewed and greatly intensified an interest in those materials. This was, at least partially, related to expectations that their Curie temperatures can be relatively easily brought to room temperature range through a clearly delineated path and, partially, due to the great successes, also commercial, of metallic version of spintronics, which earned its founders the Nobel Prize in 2007. The semiconductor version of spintronics has attracted researchers also because of hopes to engage it in efforts to construct quantum information processing devices. While these hopes and expectations are not fully realized yet, the effort is going on.

As a good example of recent achievements, new results on quantum dots containing a single magnetic ion should be mentioned. A great progress has been achieved in studies of excitonic states in such quantum dots, so far limited to InAs/GaAs [3, 4] and CdTe/ZnTe [5, 6] material systems and to Manganese as the magnetic ion. Furthermore, in the II–VI QDs, first results on the optical control of the Mn spin states have been experimentally demonstrated [7–9] and theoretically analyzed [10]; the studies of Mn spin dynamics and control in III–V QDs will certainly follow. Similarly, a considerable effort is directed toward growth and characterization of another "fashionable" objects of nanotechnology, namely nanorods mostly grown by vapor–liquid–solid technique, composed, e.g., of ZnMnTe. The research on DMS nanorods and structures made of those objects is currently very actively developed, see, e.g., [11].

With such a tremendous interest worldwide, of course, there appeared several books with excellent reviews on physics and potential applications of diluted magnetic semiconductors [12–18] (including skeptical reviews, [19,20]). Also, the "old" materials such as II–VIs with transition metal ions are already covered extensively in several books, data collections etc. [21–29]. Therefore, it seems that there is little room for yet another book on a similar subject. However, the collection of previous articles seemed to share one feature: they were devoted to, at the time of their appearance, most recent achievements in the field. On the other hand, a systematic, pedagogical approach to the basics of physics of diluted magnetic semiconductors was, in our opinion, conspicuously missing. This is particularly true in the case of low-dimensional structures composed of diluted magnetic semiconductors. This book intends to fill this gap, without dropping entirely an ambition to speak about the recent achievements and research directions, such as time-resolved investigations of spin dynamics. Whether or not we succeeded in reaching this goal remains to be judged by the readers.

Since both editors of this volume consider experiment to be a driving force in the area of present interest, it was our intention to start with chapters that stressed the experimental facts and issues with theoretical explanations and ideas to follow.

The history of diluted magnetic semiconductors can be traced down to research on ferromagnetic spinels with Cr and Eu chalcogenides [30] mostly at IBM Research Center roughly in the sixties of the previous century. One must note early theoretical ideas concerning magnetic polarons and spin molecules, as well as spin-dependent scattering and indirect coupling via carriers. These can be viewed as precursors of the field of diluted magnetic semiconductors. However, it was only when magnetic components (Manganese ions, in most of the cases) were started to be introduced into relatively simple semiconductor matrices, such as CdTe, that the field began to gain impetus in mid-seventies of the twentieth century. Motivations to introduce Manganese was certainly different: it was hoped that (Hg,Mn)Te would be mechanically more durable than (Hg,Cd)Te – the material for infrared detectors made of narrow gap semiconductors, or it was hoped that electron resonances would become detectable in the internal effective field (rather than in the external magnetic filed), or that addition of Mn to HgTe would result in particularly high electron mobility in such ternary materials (as found in early work of Morissy in his Ph.D. thesis in Oxford). Furdyna hoped to detect spin resonance of Mn in highly conductive HgTe exploiting transmission of helicon waves in a magnetic field [31]. Not all of those ideas survived the test of time. But, without doubt, it was discovery of very pronounced magnetooptical activity of these materials, particularly of the giant Faraday rotation (whose origin was traced down to giant Zeeman splitting) of excitonic states in CdMnTe [32, 33] that sparked a broader interest. It was during the ICPS in Edinburgh in 1978 that the first invited talk on diluted magnetic semiconductors was given [34].

As mentioned, there are several review volumes or chapters devoted to the early work on physics of diluted magnetic semiconductors. Without attempting to be exhaustive, let us mention additionally [35] and references therein. We are also aware that while this volume is being prepared, a team of authors just completed preparation of a comprehensive book describing the spintronics-related physics of ferromagnetic III–V-based diluted magnetic semiconductors that are most popular these days [15]. Partly for this reason, this book, apart from attempting to have a pedagogical character, concentrates on "orthodox" II–VI diluted magnetic semiconductors since we believe that all basic ideas can be introduced using examples from that thoroughly studied group of materials. We hope also to reduce duplication of the material with our choice. A certain emphasis is put on low-dimensional structures, quantum wells and quantum dots, and on phenomena that only recently started to be accessible experimentally, e.g., spin relaxation and coherence.

With all these remarks in mind, the structure of the volume is the following: we begin with what we consider a most rudimentary Chap. 1 which may serve as an introduction to the field suitable for students just entering the field. We present there the simplest mean field approach that provides an acceptable description in many cases and was the first that was historically used. The next Chap. 2, by Pacuski, deals with those materials – semiconductors with wide gap between the valence band and the conduction band – where apart from apparent similarities such a simple mean field/virtual crystal approximation evidently does not work. Merkulov and Rodina in the next Chap. 3 to provide the reader with a very general and thorough theoretical considerations concerning the very origins of the specificity of diluted magnetic semiconductors, namely the spin-dependent coupling between the valence and conduction band carriers and electrons localized on half-filled shell of the "magnetic" ions, such as Manganese. In particular, an attention is paid to the role of dimensionality in the physics of this interaction. In the next Chap. 4, Furdyna and coworkers introduce us to the realm of experiments on low-dimensional structures such as quantum wells, superlattices (in particular, spin superlattices), etc. This is followed by a special Chap. 5 by Henneberger and Puls devoted to quantum dots that are either embedded in the magnetic environment or are magnetic themselves. In the spirit of the book (experiments first, theories – later) Chap. 6 contributed by Hawrylak gives a thorough discussion of the $sp-d$ coupling in the specific case of the quantum dots paying attention to many body aspects of the problem. When talking about dots, it is impossible not to mention magnetic polarons, localized magnetic polarons in particular, which constitute the topic of Chap. 7 by Yakovlev and Ossau. Temporal behavior of various degrees of freedom are discussed in next two Chaps. 8 and 9, first, by Yakovlev and Merkulov, discusses the relaxation of spins in diluted magnetic semiconductors, while the second, by Crooker, concentrates on the coherence of precessing spins in the DMS structures, something that may be of importance in quantum information processing in diluted magnetic semiconductor spintronic qubits. Many body aspects of optical properties (Chap. 10 by Perez and Kossacki) and charge transport (Chap. 11 by Jaroszyński) are covered next. Finally, Giebultowicz and Kępa (Chap. 12) provide us with a detailed discussion of the interlayer coupling in diluted magnetic superlattices with non-magnetic interlayers as seen by neutron scattering experiments.

As mentioned, there is some degree of topical overlap between the chapters. We found it very difficult (although we did try) to keep the notation exactly the same in the whole book (e.g., the exchange constant α needs to have, sometimes, additional super or subscripts, and sometimes it does not, when the approach is made simpler). Although this may be viewed as incompatible with an intended pedagogical spirit of the present volume, we tend to agree that that some variations of notation among the chapters is possible, provided that they are explained properly in the text, since they reflect the authors' varying views concerning the importance of particular aspects of the physics in question.

As we saw in the past, the motivations to study a fascinating class of materials, such as DMSs, might vary in time. At present, it is spintronics and quantum computation that are the driving forces. It is, thus, not unreasonable to expect that new stimuli will appear also in the future, e.g., located at the interface of spin physics and life sciences. We think, therefore, that an effort to study DMSs represents a good investment. We hope that the present collection of chapters will help the reader in this task.

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Jan Gaj
Jacek Kossut

References

1. H. Munekata et al., Phys. Rev. Lett. **63**, 1849 (1989)
2. H. Ohno et al., Phys. Rev. Lett. **68**, 2662 (1992)
3. O. Krebs et al., Phys. Rev. B **80**, 165315 (2009)
4. J. van Bree et al., Phys. Rev. B **78**, 165414 (2008)
5. Y. Leger et al., Phys. Rev. Lett. **97**, 107401 (2006)
6. L. Besombes et al., Phys. Rev. B **78**, 125324 (2008)
7. C. Le Gall et al., Phys. Rev. Lett. **102**, 127402 (2009)
8. M. Goryca et al., Phys. Rev. Lett. **103**, 087401 (2009)
9. C. Le Gall et al., Phys. Rev. B **81**, 245315 (2010)
10. D.E. Reiter, T. Kuhn, V.M. Axt, Phys. Rev. Lett. **102**, 177403 (2009)
11. W. Zaleszczyk et al., Nano Lett. **8**, 4061 (2008)
12. D.D. Awschalom, D. Loss, N. Samarth (eds.), *Semiconductor Spintronics and Quantum Computations* (Springer, Berlin, 2002)
13. D.D. Awschalom, R.A. Buhrman, J.M. Daughton, S. von Molnár, M.L. Roukes (eds.), *Spin Electronics* (Kluver, Dordrecht, 2004)
14. M. Ziese, J. Thornton (eds.), *Spin Electronics* (Springer, Berlin, 2001)
15. T. Dietl, D.D. Awschalom, M. Kamińska, H. Ohno (eds.), *Spintronics*, in *Semiconductors and Semimetals*, vol 82 (Elsevier, Amsterdam, 2008)
16. J. Fabian, I. Zutic, S. Das Sarma, Rev. Mod. Phys. **76**, 323 (2004)
17. J. Fabian, A. Matos-Abiague, C. Ertler, P. Stano, I. Zutic, Acta Phys. Slovaca, **4**, 565 (2007)
18. see also special issue of *Semiconductor Science and Technology*, ed. by H. Ohno, vol 17, issue 4, 2002
19. M.I. Dyakonov, in *Future Trends in Microelectronics: The Nano, The Giga, and the Ultra*, eds. by S. Luryi, J. Xu, A. Zaslavski (Wiley, NY, USA, 2004, cond-mat/0411672), p. 157
20. M.I. Dyakonov, in *Future Trends in Microelecronics: The Nano Millenium*, eds. by S. Luryi, J. Xu, A. Zaslavski (Wiley, NY, USA, 2002, cond-mat/0110326), p. 307
21. R.R. Gałązka, J. Kossut, in *Landolt-Börnstein*, ed. by O. Madelung, vol 17b (Springer, Berlin, 1982)
22. R.R. Gałązka, J. Kossut, T. Story, in *Landolt-Börnstein*, vol 41 (Springer, Berlin, 1999), p. 650
23. J. Kossut, W. Dobrowolski, in *Handbook of Magnetic Materials*, ed. by K.H.J. Buschow, vol 7 (North Holland, Amsterrdam, 1993), p. 231
24. J. Kossut, W. Dobrowolski, T. Story, in *Handbook of Magnetic Materials*, ed. by K.H.J. Buschow, vol 15 (North Holland, Amsterdam, 2003), p. 289
25. J.K. Furdyna, J. Kossut (eds.), vol 25 of *Semiconductors and Semimetals* (Academic Press, Boston, 1988) (Russian translation: Mir, Moskva, 1992)
26. J.K. Furdyna, J. Appl. Phys. **64**, R29 (1988)

27. T. Dietl, in *Handbook of Semiconductors*, eds. by T.S. Moss, S. Mahajan (Elsevier, Amsterdam, 1997), p. 1521
28. J. Kossut, W. Dobrowolski, in *Narrow Gap II–VI Compounds for Optoelectronic and Electromagnetic Applications*, ed. by P. Capper (Chapman and Hall, London, 1997), p. 401
29. M. Jain (ed.), *Diluted Magnetic Semiconductors* (World Scientific, Singapore, 1991)
30. See special volume of IBM J. Res. Develop. **14**, 3 (1970)
31. J. Furdyna, R.T. Holm, Phys. Rev **15**, 844 (1977)
32. J.A. Gaj, R.R. Gałązka, M. Nawrocki, Solid State Commun. **25**, 193 (1978)
33. A.V. Komarov, S.M. Ryabchenko, O.V. Terletskii, I.I. Zheru, R.D. Ivanchuk, Pis'ma v Zh. Eksp. Teor. Fiz. **73**, 608 (1977) (Sov. Phys. JETP **46**, 318)
34. R.R. Gałązka, in *Proc. 14th Internat. Conf. Phys. Semicond, Edinburgh, 1978*, ed. by B.L.H. Wilson, (Internat. Conf. Series vol 43), (Institute of Physics, London, 1978), p. 133
35. N.B. Brandt, V.V. Moshchalkov, Adv. Phys. **33**, 193 (1984)

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