All-optical spin locking in alkali-vapor magnetometers

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High-sensitivity magnetometers are used in a wide variety of applications ranging from geophysics [1] to fundamental physics [2,3] and medicine [4,5]. Alkali-metal-vapor atomic magnetometers have seen tremendous progress in recent years improving their sensitivities to below the $\mathrm{fT}/\sqrt{\mathrm{Hz}}$ level [1,6-9] at submicrotesla fields. However, in the geophysical field range (up to $100\,\mu$T), the main limitation to the magnetic-resonance linewidth and sensitivity is the nonlinear Zeeman (NLZ) effect [10-12], which causes splitting of different components of the magnetic-resonances as well as lineshape asymmetries. We demonstrate a scheme to suppress the nonlinear Zeeman effect all optically based on spin locking. Spin locking is achieved with an effective oscillating magnetic field provided by the AC Stark-shift of an intensity-modulated and polarization-modulated laser beam. This results in the collapse of the multi-component asymmetric magnetic-resonance line with ~ 100 Hz width in the Earth-field range into a single peak with a width of 25 Hz as shown in figure 1. (c). The technique is expected to be broadly applicable in practical magnetometry, potentially boosting the sensitivity and accuracy of Earth-surveying magnetometers by increasing the magnetic-resonance amplitude and decreasing its width. An additional advantage of an all-optical approach is the absence of cross-talk between nearby sensors when these are used in a gradiometric arrangement.

[1] I. Gerhardt and R. Löw, A new era for hot atom spectroscopy, New York Times, **012318**, 1 (2018).
[2] J. Kitching, S. Knappe and L. Hollberg, Miniature vapor-cell atomic-frequency references, APL **81**, 553 (2002).
[1] H. Dang, A. Maloof, and M. Romalis, Applied Physics Letters **97**, 151110 (2010).
[2] G. Vasilakis, J. Brown, T. Kornack, and M. Romalis, Physical review letters **103**, 261801 (2009).
[3] I. Altarev, C. Baker, G. Ban, G. Bison, K. Bodek, M. Daum, P. Fierlinger, P. Geltenbort, K. Green, M. Van Der Grinten, et al., Physical review letters **103**, 081602 (2009).
[4] G. Bison, N. Castagna, A. Hofer, P. Knowles, J.-L. Schenker, M. Kasprzak, H. Saudan, and A. Weis, Applied Physics Letters **95**, 173701 (2009).
[5] C. N. Johnson, P. Schwindt, and M. Weisend, Physics in medicine and biology **58**, 6065

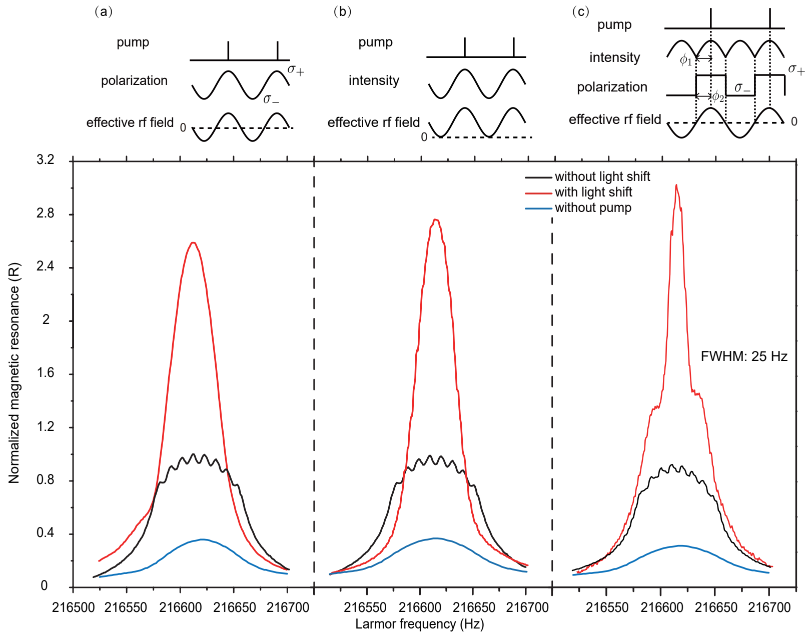

Figure 1. Magnetic-resonance lineshape for a modulation frequency of 216,620 Hz as a function of the leading magnetic field along the $\hat{z}$-axis with applied light-shift field and pump (red line), without light-shift field (black line), and without pump field (blue line). The amplitude of magnetic resonance without light shift is normalized to one. The power in (a) and maximum power in (b,c) of the light-shift beam is 200 mW. The inset shows the polarization modulation (a), intensity modulation (b) and modulated both (c) scheme for the pump and light-shift field.

(2013).
[6] M. Ledbetter, I. Savukov, V. Acosta, D. Budker, and M. Romalis, Physical Review A **77**, 033408 (2008).
[7] W. C. Griffith, S. Knappe, and J. Kitching, Optics express **18**, 27167 (2010).
[8] S. Smullin, I. Savukov, G. Vasilakis, R. Ghosh, and M. Romalis, Physical Review A **80**, 033420 (2009).
[9] D. Budker and M. Romalis, Nature Physics **3**, 227 (2007).
[10] S. Seltzer, P. Meares, and M. Romalis, Physical Review A **75**, 051407 (2007).
[11] V. Acosta, M. Ledbetter, S. Rochester, D. Budker, D. J. Kimball, D. Hovde, W. Gawlik, S. Pustelny, J. Zachorowski, and V. Yashchuk, Physical Review A **73**, 053404 (2006).
[12] K. Jensen, V. Acosta, J. Higbie, M. Ledbetter, S. Rochester, and D. Budker, Physical Review A **79**, 023406 (2009).