Spin Torque–Generated Magnetic Droplet Solitons

S. M. Mohseni *et al.*

Science **339**, 1295 (2013);
DOI: 10.1126/science.1230155

Science (print ISSN 0036-8075; online ISSN 1095-9203) is published weekly, except the last week in December, by the American Association for the Advancement of Science, 1200 New York Avenue NW, Washington, DC 20005.

frequency ($f_{droplet}$) should increase linearly with field at a slope of $g/2p$ (g is the gyromagnetic ratio, so $g/2p$ = 28.7 GHz/T) and decrease very weakly with current, which is in agreement with Fig. 1, A and B, respectively.

From the MR value at the transition, we can conclude that the Co layer tilt angle required to nucleate a droplet at –6 mA is ~50°. Assuming that the nucleation is primarily driven by the perpendicular component of the spin-polarized current density, we expect the required nucleation current to be inversely proportional to the perpendicular component M_z of the fixed layer magnetization. Because M_z is linearly proportional to the perpendicular field for the easy-plane Co (fig. S1) (22), we can directly test this assumption by plotting the nucleation current ($I_{droplet}$) versus inverse applied field, $1/H$ (Fig. 1D). We indeed observed that $I_{droplet}$ is inversely proportional to the applied field and that the slope of this dependence scales with NC area, confirming that the droplet nucleation is governed by the perpendicular component of the spin-polarized current density, regardless of the applied field and NC size.

We now turn to the modulation sidebands that appear simultaneously with the nucleation of the magnetic droplet. The droplet and its field dependence are very robust and reproducible from device to device; however, we found greater variation in the modulation, with some devices showing single (Fig. 2A) and multiple (Fig. 2B) well-defined sideband pairs, some showing strong peaks at $f_{droplet}$

the experimentally observed modulation sidebands. However, this explanation is not consistent with the observed hysteresis (Fig. 2B), predicted for stable, nondrifting droplets (13), because it precludes the periodic death and rebirth of the droplet. Upon decrease of the current below the nucleation threshold, a new droplet cannot form once the first droplet has disappeared. Micromagnetic simulations reveal two possible explanations for this discrepancy relying on the presence of a sufficiently canted polarizer for moderate fields. The drifting drop-

References and Notes

1. . . A , A. A , . 751, 1 (2008).
2. . . , . D. , . 15, 240 (1965).
3. . B. , . , C. . , . 81, 2236 (1998).
4. . B ., 419, 699 (2002).
5. . . , D. , . 70, 830 (1993).
6. . . , . , G. E , G. E , A. , . 66, 3083 (1991).
7. . B. , F. , . . , 382, 793 (1996).
8. F. , . D , . 71, 3283 (1993).
9. . C. , . . . 159, 1 (1996).
10. . C. , . . . 195, 261 (1999).
11. . B , . *B* 54, 9353 (1996).
12. D. , . , . . . 320, 1190 (2008).
13. . A. , . . , . . , . *B* 82, 054432 (2010).
14. . A. , . , 241, 890 (2012).
15. . A. , . , . . , . *B* 85, 214433 (2012).
16. B. A. , A. . , . . . 72, 2000 (1977).
17. A. . , B. A. , A. . , . . 194, 117 (1990).
18. A. , . , . 95, 237201 (2005).
19. . B ., . 105, 217204 (2010).
20. . . ., . *B* 81, 014426 (2010).
21. . . ., . 5, 432 (2011).
22. .
23. . . , . . , . , . . , . E. , *A* . . 86, 082506 (2005).
24. . . ., . *B* 81, 140408( ) (2010).
25. . . B , . E. D , . A. , . *A* 184, 198 (1994).
26. . ., *A* . . 95, 192507 (2009).
27. . B , G. , . , . . . 72, 159 (2011).
28. . . , . . D , D. G , . *A* . . 43, 264001 (2010).