The recent discovery of ferromagnetism in two-dimensional (2D) van der Waals (vdW) materials holds promises for spintronic devices with exceptional properties. However, to use 2D vdW magnets for building spintronic nanodevices such as magnetic memories, key challenges remain in terms of effectively switching the magnetization from one state to the other electrically. Here, we devise a bilayer structure of Fe$_3$GeTe$_2$/Pt, in which the magnetization of few-layered Fe$_3$GeTe$_2$ can be effectively switched by the spin-orbit torques (SOTs) originated from the current flowing in the Pt layer. The effective magnetic fields corresponding to the SOTs are further quantitatively characterized using harmonic measurements. Our demonstration of the SOT-driven magnetization switching in a 2D vdW magnet could pave the way for implementing low-dimensional materials in the next-generation spintronic applications.

**RESULTS**

We fabricated the FGT/Pt device by first exfoliating few-layered FGT flakes from a high-quality bulk crystal onto Si/SiO$_2$ substrates. Characterizations of the magnetic properties and the structure of bulk FGT are shown in section S1. Figure 1C shows a representative high-angle annular dark-field scanning transmission electron microscopy (STEM) image of the as-exfoliated FGT. Atomic arrangements in the [100] axes are in agreement with the crystal structure of FGT. Each layer is constituted by the alternately arranged Te–Fe–Ge(Fe)–Fe–Te atomic planes. The vdW gaps (dark area) are visible between different layers. The exfoliated FGT flakes show a minimum step height of 0.8 nm on the surface (Fig. 1, D and E), which matches an atomic layer thickness of FGT. After exfoliating the FGT flakes, we immediately transferred the substrates into a high-vacuum sputtering system and then deposited a 6-nm-thick Pt layer on top of FGT. We then patterned the FGT/Pt bilayers into Hall bar devices (see Fig. 1F) by the processes described in section S2.

We first measured the resistance of the device as a function of temperature, as shown in Fig. 1G. The bilayer device exhibits a metallic behavior. To elucidate the resistance behavior of FGT, we separately characterize the temperature-dependent resistivity of Pt layer by measuring a Hall bar control device prepared on a Si/SiO$_2$ substrate. Considering the geometry and thickness of the Pt layer in the FGT/Pt device, the resistance contribution from the Pt layer can be deducted (see fig. S14) so that the resistance of FGT can be roughly extracted (see Fig. 1G). The temperature dependence of the FGT resistance is similar to the previous reports for FGT with four to six layers (3.2 to 4.8 nm) (21). The actual layer number observed by TEM is larger, as shown in Fig. 1B. We attribute this difference to the oxidation of FGT.
We then characterized the magnetic properties of our devices by measuring the Hall resistances. Figure 2A shows the Hall resistance as a function of the out-of-plane magnetic fields at various temperatures. Because of the intrinsic magnetization of FGT, anomalous Hall resistance dominates over the total Hall resistance below $T_c$ as indicated by the square-shaped loops. The hysteresis loop gradually disappears, and the Hall resistance curve becomes more linear with increasing the temperature. The $T_c$ of our device is determined to be $\sim$158 K by performing the Arrott plots ($21, 23$), as shown in Fig. 2B. Compared to the previously reported layer-dependent $T_c$ ($21$), the obtained $T_c$ in our FGT corresponds to approximately five layers (4 nm). This thickness value is in consistent with the estimations from the resistance measurements and the TEM image. Below $T_c$, the device exhibits PMA, as manifested by the much larger saturation field in the in-plane direction than that in the out-of-plane direction (Fig. 2C).

Next, we show that a current flowing in the bilayer can generate SOTs, which are originated from the spin Hall effect in Pt and/or the interfacial effects. The SOTs are characterized through harmonic measurements ($24, 25$). For the harmonic measurements, a small ac is applied to the device in the presence of an in-plane external magnetic field along the longitudinal (transverse) direction for measuring longitudinal (transverse) effective fields. Figure 3 shows the measured harmonic voltages under longitudinal ($H_L$) (A and B) and transverse ($H_T$) (D and E) external magnetic fields, which are fitted by parabolic and linear functions, respectively. The ratios corresponding to damping-like and field-like torques can be calculated as $B_{L(T)} = -2 \left( \frac{\partial^2 V_{2\omega}}{\partial H_L^2(T)} \right) / \frac{\partial V_{\omega}}{\partial H_L(T)}$. Here, $V_{\omega}$ and $V_{2\omega}$ are the first and second harmonic...
The spin torque efficiency is given by

$$\eta = \frac{\Delta R_H}{\Delta R_H}$$

where $\Delta R_H$ is the change in Hall resistance and $\Delta R$ is the change in resistance. This efficiency is used to calculate the effective field $H_{eff}$ using

$$H_{eff} = \frac{\eta}{M_s}$$

where $M_s$ is the saturation magnetization. The effective field is then used to calculate the switching current $I_s$ using

$$I_s = \frac{H_{eff}}{\mu_0 M_s}$$

where $\mu_0$ is the permeability of free space.

The switching current $I_s$ is obtained by solving the above equation for $I$. The result is then compared with the measured switching current to determine the efficiency of the device. The switching current is given by

$$I_s = \frac{H_{eff}}{\mu_0 M_s}$$

where $H_{eff}$ is the effective field and $M_s$ is the saturation magnetization. The switching current $I_s$ is then used to determine the efficiency of the device.

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proof-of-concept SOT devices highlight the potential of magnetic vdW materials and their compatibilities with spintronic technologies. Further work is still needed to push the FGT down to the monolayer limit. Other than the Pt or Ta used in this work, vdW materials with strong spin-orbit coupling and nontrivial electronic properties can also be used as SOT sources, leading to the possible all-vdW magnetic memories. The large family of vdW materials and numerous combinations of vdW heterostructures remarkably extend the material choices and can be visioned as new building blocks for spintronic applications in the near future.

Fig. 3. Characterization of the current-induced effective fields. (A and B) First and second harmonic voltages for the longitudinal effective field. $H_L$ is the applied longitudinal magnetic field along the current direction ($x$ axis). (D and E) First and second harmonic voltages for the transverse effective field. $H_T$ is the applied transverse magnetic field transverse to the current direction ($y$ axis). (C and F) Plots of the longitudinal and transverse field as a function of the peak current. The solid lines represent the linear fitting result with zero intercept. The red circles (blue squares) are data points for the $M_z > 0$ ($M_z < 0$). In the bilayer device, applying a current of 1 mA corresponds to a current density of $1.85 \times 10^{10}$ A/m$^2$ in the Pt layer.

Fig. 4. SOT-driven perpendicular magnetization switching in the FGT/Pt bilayer device. Current-driven perpendicular magnetization switching for in-plane magnetic fields of 50 mT (A) and −50 mT (B) at 100 K. The switching polarity is anticlockwise and clockwise, respectively. The dashed lines correspond to the $R_{\text{AHE}}$ at saturated magnetization states. (C) Current-driven perpendicular magnetization switching with a 300-mT in-plane magnetic field at 10 K (red). The arrows indicate the current sweeping direction. The initial state is saturated in the positive direction. The current increases gradually in the positive direction, and the $R_{\text{AHE}}$ jumps down to an intermediate state. The two states in the switching loop do not correspond to the saturated states. The device temperature during the application of switching current (blue) is obtained by comparing the measured longitudinal resistance and the measured $R_{xxT}$ curve (fig. S14). The dashed line corresponds to the $T_c$ obtained from the Arrott plots. (D) Switching-phase diagram with respect to the in-plane magnetic fields and critical switching currents at different temperatures. The critical switching current decreases with increasing temperature. In the bilayer device, applying a current of 1 mA corresponds to a current density of $1.85 \times 10^{10}$ A/m$^2$ in the Pt layer.
MATERIALS AND METHODS

Growth and characterization of FGT bulk crystal

Single crystals of FGT were prepared by chemical vapor transport (CVT) method with iodine as the transport agent. High-purity (99.99%) Fe, Ge, and Te were milled into powder form with a stoichiometric molar proportion of 3:1.2 (Fe:Ge:Te) in an agate mortar.

Device fabrication

We obtained few-layered FGT flakes with a freshly cleaved surface on Si/SiO₂ substrate by our new developed scratching method (refer to section S2) through our home-made transfer station. Next, we deposited a 6-nm-thick Pt [or Ta (6 nm)/Pt (1.5 nm)] layer on the FGT surface, and the obtained FGT/Pt bilayer is air-stable and this could confirm the subsequent fabrication process. The Pt/FGT bilayer was patterned as Hall geometry by a standard e-beam lithography process, and excretion areas were etched by ion milling. Last, the electrodes were fabricated by Ti (3 nm)/Au (50 nm) through e-beam evaporation.

Characterizations

We used aberration-corrected STEM to image the cross sections directly. The cross-sectional samples were fabricated by focused ion beam cutting along the [100] axes of FGT. All the electrical measurements were performed in a Physical Property Measurement System (PPMS) system with magnetic fields of up to 9 T and temperatures down to 1.8 K. Multiple lock-in amplifiers (Stanford SR830 and SR850) and Keithley source meters (Keithley 2400, 2182, and 6221) were connected to the PPMS, enabling comprehensive transport measurements for the Hall bar devices. A constant of 200 µA dc was applied for the Hall measurement. In the switching measurement, large current pulses (write current, 50 ms) were first applied. After a time interval of 100 ms, we subsequently applied another small current (read current, 0.1 mA for 50 ms), during which the Hall voltage signal was picked up. The device temperature during the application of write pulse was extracted by monitoring the longitudinal resistance. The temperature increased during the application of read pulse was negligible.

SUPPLEMENTARY MATERIALS

Supplementary material for this article is available at http://advances.sciencemag.org/cgi/content/full/5/8/eaaw8904/DC1

Section S1. Crystal growth and characterization

Section S2. Exfoliation of FGT thin flakes and fabrication of FGT/Pt bilayer devices

Section S3. Correction of current-induced effective fields

Section S4. Current-driven switching at different temperatures

Section S5. Current-driven magnetization switching

Section S6. Current-driven magnetization switching and measurement of effective fields corresponding the current-induced torques

Section S7. Temperature dependence of PMA

Fig. S1. Single crystals of FGT at the colder side in a sealed quartz tube (diameter of the tube is 1.5 cm).

Fig. S2. Characterization of FGT single crystal grown by CVT method.

Fig. S3. Zero-field–cooling and field-cooling curves of the FGT crystals (grown by CVT) measured from 10 to 300 K with the external magnetic field (\(H = 0.1\ T\)) parallel to the c axis.

Fig. S4. Hysteresis loops measured of the FGT crystals (grown by flux method) at various temperatures with the external magnetic field parallel to the c axis.

Fig. S5. Zero-field–cooling and field-cooling curves of the FGT crystals (grown by flux method) measured from 10 to 300 K with the external magnetic field (\(H = 0.1\ T\)) parallel to the c axis.

Fig. S6. Hysteresis loops of the FGT crystals (grown by CVT method) measured at various temperatures with the external magnetic field parallel to the ab plane.

Fig. S7. Zero-field–cooling and field-cooling curves of the FGT crystals (grown by CVT) measured from 10 to 300 K with the external magnetic field (\(H = 0.1\ T\)) parallel to the ab plane.

Fig. S8. Characterization of FGT single crystal grown by flux method.

Fig. S9. Zero-field–cooling and field-cooling curves of the FGT crystals (grown by flux method) measured from 10 to 300 K with the external magnetic field parallel to the c axis.

Fig. S10. Hysteresis loops measured of the FGT crystals (grown by CVT) at various temperatures with the external magnetic field parallel to the c axis.

Fig. S11. Schematic view of FGT exfoliation, transfer, and device fabrication process.

Fig. S12. Atomic force microscopy image of the obtained FGT flakes on SiO₂ substrate through two strategies.

Fig. S13. Optical image of the device fabrication process.

Fig. S14. Estimation of the temperature dependence of the resistance of FGT layers.

Fig. S15. Schematic diagram of measurement setup and coordinate system.

Fig. S16. Current-driven switching at 10 K.

Fig. S17. Current-driven switching at 20 K.

Fig. S18. Current-driven switching at 30 K.

Fig. S19. Current-driven switching at 40 K.

Fig. S20. Current-driven switching at 50 K.

Fig. S21. Current-driven switching at 60 K.

Fig. S22. Current-driven switching at 70 K.

Fig. S23. Current-driven switching at 80 K.

Fig. S24. Current-driven switching at 90 K.

Fig. S25. Current-driven switching at 100 K.

Fig. S26. Current-driven switching at 110 K.

Fig. S27. Current-driven switching at 120 K.

Fig. S28. Current-driven switching at 130 K.

Fig. S29. \(R_p\) as a function of current under different in-plane magnetic field at 140 K.

Fig. S30. Current-driven magnetization switching for different initial states.

Fig. S31. Current-driven switching in an FGT/Ta bilayer.

Fig. S32. Characterization of the current-induced effective fields in an FGT/Ta device.

Fig. S33. Hall resistance as a function of in-plane magnetic field.

Fig. S34. Temperature dependence of effective anisotropy field (\(\mu_0H_{K}\)), coercivity (\(\mu_0H_{c}\)), and saturation anomalous Hall resistance. (References 23–25)

REFERENCES AND NOTES

1. F. Hellman, A. Hoffmann, T. Tserkovnyak, G. S. D. Beach, E. E. Fullerton, C. Leighton, A. H. MacDonald, D. C. Ralph, D. A. Arena, H. A. Dian, P. Fischer, J. Grollier, J. P. Heremans, T. Jungwirth, A. V. Kimel, B. Koopmans, I. N. Krivorotov, S. J. May, A. K. Petford-Long, J. M. Rondinelli, N. Samarth, I. K. Schuller, A. N. Slavin, M. D. Stiles, O. Tchernyshyov, A. Thiaville, B. L. Zink, Interface-induced phenomena in magnetism. Rev. Mod. Phys. 89, 025006 (2017).

2. A. Soumyanarayanan, N. Reyren, A. Fert, C. Panagopoulos, Emergent phenomena induced by spin-orbit coupling at surfaces and interfaces. Nature 539, 509–517 (2016).

3. J. Nogués, I. K. Schuller, Exchange bias. J. Magn. Magn. Mater. 192, 203–232 (1999).

4. B. Dieny, M. Chshiev, Perpendicular magnetic anisotropy at transition metal/oxide interfaces and applications. Rev. Mod. Phys. 89, 025008 (2017).

5. S. Ikeda, K. Miura, H. Yamamoto, K. Mizunuma, H. D. Gan, M. Endo, S. Kanai, J. Hayakawa, F. Matsukura, H. Ohno, A perpendicular-anisotropy CoFeB-MgO magnetic tunnel junction. Nat. Mater. 9, 721–724 (2010).

6. J. C. Słonczewski, Current-driven excitation of magnetic multilayers. J. Magn. Magn. Mater. 159, L1–L7 (1996).

7. L. Berger, Emission of spin waves by a magnetic multilayer traversed by a current. Phys. Rev. B 54, 9353–9358 (1996).

8. A. Brataas, A. D. Kent, H. Ohno, Current-induced torques in magnetic materials. Nat. Mater. 11, 372–381 (2012).

9. I. I. Miron, K. Garello, G. Gaudin, P. J. Zermatten, M. V. Costache, S. Auffret, S. Bandiera, J. M. Rondinelli, N. Samarth, I. K. Schuller, A. N. Slavin, M. D. Stiles, O. Tchernyshyov, A. Thiaville, B. L. Zink, Interface-induced phenomena in magnetism. Rev. Mod. Phys. 89, 025006 (2017).

10. S. Ikeda, J. Hayakawa, Y. M. Lee, F. Matsukura, H. Ohno, A perpendicular-anisotropy CoFeB-MgO magnetic tunnel junction. Nat. Mater. 9, 721–724 (2010).

11. J. C. Słonczewski, Current-driven excitation of magnetic multilayers. J. Magn. Magn. Mater. 159, L1–L7 (1996).

12. L. Berger, Emission of spin waves by a magnetic multilayer traversed by a current. Phys. Rev. B 54, 9353–9358 (1996).

13. A. Brataas, A. D. Kent, H. Ohno, Current-induced torques in magnetic materials. Nat. Mater. 11, 372–381 (2012).

14. I. I. Miron, K. Garello, G. Gaudin, P. J. Zermatten, M. V. Costache, S. Auffret, S. Bandiera, B. Rodmacq, A. Schuhl, P. Gambardella, Perpendicular switching of a single ferromagnetic layer induced by in-plane current injection. Nature 476, 189–193 (2011).

15. L. Liu, F. Pai, Y. Li, H. W. Tseng, D. C. Ralph, R. A. Buhrman, Spin-torque switching with the giant spin Hall effect of tantalum. Phys. Rev. Lett. 105, 057602 (2011).

16. S. Ikeda, J. Hayakawa, Y. M. Lee, F. Matsukura, H. Ohno, A perpendicular-anisotropy CoFeB-MgO magnetic tunnel junction. Nat. Mater. 9, 721–724 (2010).

17. J. C. Słonczewski, Current-driven excitation of magnetic multilayers. J. Magn. Magn. Mater. 159, L1–L7 (1996).

18. L. Berger, Emission of spin waves by a magnetic multilayer traversed by a current. Phys. Rev. B 54, 9353–9358 (1996).
13. C. Gong, L. Li, Z. Li, H. Ji, A. Stern, Y. Xia, T. Cao, W. Bao, C. Wang, Y. Wang, Z. Q. Qiu, R. J. Cava, S. G. Louie, J. Xia, X. Zhang, Discovery of intrinsic ferromagnetism in two-dimensional van der Waals crystals. Nature 546, 265–269 (2017).

14. D. R. Klein, P. MacNeill, J. L. Lado, D. A. Belden, K. Watanabe, T. Taniguchi, S. Manni, P. Canfield, J. Fernández-Rossier, P. Jarillo-Herrero, Probing magnetism in 2D van der Waals crystalline insulators via electron tunneling. Phys. Rev. Lett. 360, 1218–1222 (2018).

15. T. C. Song, X. Cai, M. W. Xu, X. Zhang, B. Huang, P. N. Wilson, K. L. Seyler, L. Zhu, T. Taniguchi, K. Watanabe, M. A. McGuire, D. H. Cobden, D. Xiao, W. Yao, X. Xu, Giant tunneling magnetoresistance in spin-valve van der Waals heterostructures. Phys. Rev. Lett. 360, 1214–1218 (2018).

16. H. H. Kim, B. Yang, T. Patel, F. Sfigakis, C. Li, S. Tian, H. Lei, A. W. Tsen, One million percent tunnel magnetoresistance in a magnetic van der Waals heterostructure. Nano Lett. 18, 4885–4890 (2018).

17. N. Sivadas, S. Okamoto, D. Xiao, Gate-controllable magneto-optic Kerr effect in layered collinear antiferromagnets. Phys. Rev. Lett. 117, 267203 (2016).

18. B. Huang, G. Clark, D. R. Klein, D. MacNeill, E. Navarro-Moratalla, K. L. Seyler, N. Wilson, M. A. McGuire, D. H. Cobden, D. Xiao, W. Yao, P. Jarillo-Herrero, X. Xu, Electrical control of 2D magnetism in bilayer CrI3. Nat. Nanotechnol. 13, 544–548 (2018).

19. S. W. Jiang, J. Shan, K. F. Mak, Electric-field switching of two-dimensional van der Waals magnets. Nat. Mater. 17, 406–410 (2018).

20. Z. Wang, T. Zhang, M. Ding, B. Dong, Y. Li, M. Chen, X. Li, J. Huang, H. Wang, X. Zhao, Y. Li, D. Li, C. Jia, L. Sun, H. Guo, Y. Ye, D. Sun, Y. Chen, T. Yang, J. Zhang, S. Ono, Z. Han, Z. Zhang, Electric-field control of magnetism in a few-layered van der Waals ferromagnetic semiconductor. Nat. Nanotechnol. 13, 554–559 (2018).

21. Y. J. Deng, Y. Yu, Y. Song, J. Zhang, N. Z. Wang, Z. Sun, Y. Y. Z. Wu, S. Wu, J. Zhu, J. Wang, X. H. Chen, Y. Zhang. Gate-tunable room-temperature ferromagnetism in two-dimensional Fe3GeTe2. Nature 563, 94–99 (2018).

22. Z. Y. Fei, H. Huang, P. Malinowski, W. Wang, T. Song, J. Sanchez, W. Yao, D. Xiao, X. Zhu, A. F. May, W. Wu, D. H. Cobden, J. H. Chu. X. Xu, Two-dimensional itinerant ferromagnetism in atomically thin Fe3GeTe2. Nat. Mater. 17, 778–782 (2018).

23. A. Arrott, Criterion for ferromagnetism from observations of magnetic isotherms. Phys. Rev. 108, 1394–1396 (1957).

24. K. Garello, I. M. Miron, C. O. Avci, F. Freimuth, Y. Mokrousov, S. Blügel, S. Auffret, O. Boulle, G. Gaudin, P. Gambardella, Symmetry and magnitude of spin-orbit torques in two-dimensional van der Waals crystals. Phys. Rev. Lett. 1218 (2018).

25. M.-H. Nguyen, D. C. Ralph, R. A. Buhrman, Spin torque study of the spin Hall conductivity and spin diffusion length in platinum thin films with varying resistivity. Phys. Rev. Lett. 113, 162507 (2010).

26. C. F. Pai, Y. X. Ou, L. H. Vilela-Leao, D. C. Ralph, R. A. Buhrman, Dependence of the thickness-dependent Curie temperatures of ultrathin magnetic heterostructures. Phys. Rev. B 89, 134425 (2014).

27. M.-H. Nguyen, D. C. Ralph, R. A. Buhrman, Spin torque study of the spin Hall conductivity and spin diffusion length in platinum thin films with varying resistivity. Phys. Rev. Lett. 113, 162507 (2010).

28. C. F. Pai, Y. X. Ou, L. H. Vilela-Leao, D. C. Ralph, R. A. Buhrman, Dependence of the thickness-dependent Curie temperatures of ultrathin magnetic heterostructures. Phys. Rev. B 89, 134425 (2014).

29. R. J. Zhang, R. F. Willis, Thickness-dependent Curie temperatures of ultrathin magnetic films: Effect of the range of spin-spin interactions. Phys. Rev. Lett. 86, 2665–2668 (2001).

30. C. A. F. Vaz, J. A. C. Bland, G. Lauhoff, Magnetism in ultrathin film structures. Rep. Prog. Phys. 71, 056501 (2008).

31. G. Q. Yu, P. Upadhyaya, Y. Fan, J. G. Alzate, W. Jiang, K. L. Wong, S. Takei, S. A. Bender, L. T. Chang, Y. Jiang, M. Lang, J. Tang, Y. Wang, Y. Tsirkovnyak, P. K. Amiri, K. L. Wang, Switching of perpendicular magnetization by spin-orbit torques in the absence of external magnetic fields. Nat. Nanotechnol. 9, 548–554 (2014).

32. S. A. Razavi, A. Razavi, D. Wu, G. Yu, Y.-C. Lai, K. L. Wong, W. Zhu, C. He, Z. Zhang, J. M. D. Coey, P. Stamenov, P. K. Amiri, K. L. Wang, Joule heating effect on field-free magnetization switching by spin-orbit torque in exchange-biased systems. Phys. Rev. Appl. 7, 024023 (2017).

33. C. O. Avci, K. Garello, M. Gabureac, A. Ghosh, A. Fuhrer, S. F. Alvarado, P. Gambardella, Interplay of spin-orbit torque and thermoelectric effects in ferromagnet/nanomaterial bilayers. Phys. Rev. B 90, 224427 (2014).

34. J. Kim, J. Sinha, M. Hayashi, M. Yamanouchi, S. Fukami, T. Suzuki, S. Miltani, H. Okano, Layer thickness dependence of the current-induced effective field vector in Ta/CoFeB/MgO. Nat. Mater. 12, 240–245 (2013).

35. W. J. Kong, C. H. Wan, B. S. Tao, C. Fang, L. Huang, C. Y. Guo, M. Irfan, X. F. Han, Study of spin-orbit torque induced magnetization switching in synthetic antiferromagnet with ultrathin Ta spacer layer. Appl. Phys. Lett. 113, 162402 (2018).

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