the criteria of $|\mathbf{M}_r|/|\mathbf{M}_s| > 0.8$ for at least the last three consecutive loops, where $\mathbf{M}_r$ is the remanent magnetization and $\mathbf{M}_s$ is the saturation magnetization.

Current pulse injection for racetrack experiments. To move the generated reversed domain along the racetrack, current pulses with a width of 10 μs were injected through contact pads patterned at either end of the track, and the current density in the Pt layer was 1.1×10^{11} A m^{-2}. To move the generated bubble skyrmion, current pulses with a width of 200 μs were injected, and the current density in the Pt layer was 0.8×10^{11} A m^{-2}. A small, constant out-of-plane field (−10 Oe) was applied after the generation of the reversed bubble skyrmion to maintain its size so that it could remain visible in wide-field MOKE microscopy.

Computational methods. First-principles spin-polarized calculations were performed using DFT and the projector augmented wave method as implemented in the Vienna ab initio simulation package (VASP)[61]. The exchange-correlation potential was treated using the generalized gradient approximation (GGA) with the Perdew−Burke−Ernzerhof functional corrected for solids[62], with the valence states $5s^2 5p^6 5d^1 6s^2 4f^7$ for Gd and $3d^7 4s^2$ for Co. The GGA+U method[63] was applied to the Gd *f* orbitals and the Co *d* orbitals with effective on-site Coulomb interaction parameter $U_{eff} = 7$ and 3 eV, respectively. A 7.103 × 7.103 × 7.103 Å^3 supercell of $GdCo_2$ (C15 Laves phases) was used, which contains 8 Gd and 16 Co atoms. A *k*-point mesh of 8 × 8 × 8 and an energy cut-off of 400 eV were applied. Our calculations showed that hydrogen solubility is higher for 1Gd3Co tetrahedral pores, so these interstitials were used to simulate hydride formation (see Supplementary Information for more details).

Magnetic coupling constants were calculated from the Heisenberg model of the exchange for nearest neighbours, which is described by the following Hamiltonian:

$$\mathcal{H} = -\frac{1}{2}\sum_{i \neq j} J_{i-j} S_i S_j \quad (1)$$

We employed Monte-Carlo simulations as implemented in the VAMPIRE atomistic code[64] to compute the temperature-dependent equilibrium magnetizations for the $GdCo_2H_x$, using a supercell of 5.78 × 5.78 × 5.78 nm^3 that contains 12,288 Co and Gd atoms. The effect of hydrogen absorption was introduced by modifying the set of exchange correlation constants from the results of ab initio calculations. System trajectories were simulated for various hydrogen concentration under constant $T = 300$ K, with 10^7 time steps (after 10^4 equilibration steps) and an integration time step of 10^{-15} s. The zero-field equilibrium magnetizations of the sublattices and the net magnetization were extracted from these trajectories.

All calculations were carried out using XSEDE computational resources[65].

Data availability

Source data are provided with this paper. The XMCD spectra that support the findings of this study are publicly available at https://doi.org/10.5281/zenodo.4831735.

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Author contributions

M.H. and G.S.D.B conceived and designed the experiments. G.S.D.B., J.C., K.L., B.Y. and J.-P.W. supervised the respective members of the study. M.H., M.U.H., D.Z., D.L. and J.Z. fabricated the samples. M.H., M.U.H. and J.Z. performed MOKE and electrical characterizations. S.S., A.C., P.G., M.V. and M.H. conducted the XMCD measurements. M.H. and F.B. processed the XMCD measurements with help from M.V. and P.G. M.H. carried out the mean-field modelling. K.K. performed the ab initio and spin dynamics calculations. M.H. set up the temperature-dependent MOKE apparatus with help from L.C. K.-Y.L. performed the structural and chemical analyses. M.H. wrote the manuscript with guidance from G.S.D.B. All authors discussed the results and commented on the manuscript.

Competing interests

The authors declare no competing interests.

Additional information

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