Dynamics of ferromagnetic bimerons driven by spin currents and magnetic fields

Laichuan Shen,1,∗ Xiaoguang Li,1,∗ Jing Xia,1 Lei Qiu,1
Xichao Zhang,1 Oleg A. Tretiakov,2 Motohiko Ezawa,3 and Yan Zhou1,†

1School of Science and Engineering, The Chinese University of Hong Kong, Shenzhen, Guangdong 518172, China
2School of Physics, The University of New South Wales, Sydney 2052, Australia
3Department of Applied Physics, The University of Tokyo, 7-3-1 Hongo, Tokyo 113-8656, Japan

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Magnetic bimeron composed of two merons is a topological counterpart of magnetic skyrmion in in-plane magnets, which can be used as the nonvolatile information carrier in spintronic devices. Here we analytically and numerically study the dynamics of ferromagnetic bimerons driven by spin currents and magnetic fields. Numerical simulations demonstrate that two bimerons with opposite signs of topological numbers can be created simultaneously in a ferromagnetic thin film via current-induced spin torques. The current-induced spin torques can also drive the bimeron and its speed is analytically derived, which agrees with the numerical results. Since the bimerons with opposite topological numbers can coexist and have opposite drift directions, two-lane racetracks can be built in order to accurately encode the data bits. In addition, the dynamics of bimerons induced by magnetic field gradients and alternating magnetic fields are investigated. It is found that the bimeron driven by alternating magnetic fields can propagate along a certain direction. Moreover, combining a suitable magnetic field gradient, the Magnus-force-induced transverse motion can be completely suppressed, which implies that there is no skyrmion Hall effect. Our results are useful for understanding of the bimeron dynamics and may provide guidelines for building future bimeron-based spintronic devices.

I. INTRODUCTION

Topologically nontrivial magnetic skyrmions have received a lot of attention, because they have small size and low depin-
ing current, and can be used as information carriers for in-
formation storage and computing applications [1–12]. Mag-
etic skyrmions have been experimentally observed in sys-
tems with bulk or interfacial Dzyaloshinskii-Moriya inter-
tion (DMI) [3–6], and can be manipulated by various methods,
such as electric currents [13–15], spin waves [16], magnetic
field gradients [17–19], magnetic anisotropy gradients [20–
24] and temperature gradients [25, 26]. In addition, various
topologically nontrivial spin textures, such as antiferromag-
etic skyrmions [27–31], ferrimagnetic skyrmions [32], anti-
skyrmions [33], and bimerons [10, 34–52], are also currently
hot topics.

Particularly, a bimeron composed of two merons can be
regarded as a counterpart of the skyrmion in in-plane mag-
nets, which can be attained by rotating the spin texture of a
skyrmion by 90◦. [43] Therefore, the ferromagnetic (FM)
bimerons share the characteristics of skyrmions, such as small
size and topologically nontrivial spin structure, and they also
show the transverse drift during force-driven motion, i.e., the
skyrmion Hall effect [53, 54]. The skyrmion Hall effect may
cause the skyrmion (or bimeron) to annihilate at the sam-
ple edge, which is detrimental for practical applications. To
overcome or suppress the skyrmion Hall effect, various ways
have been proposed, such as adopting synthetic antiferromag-
etic skyrmions [55–58] or applying high magnetic anisotropy
in the racetrack edge [59]. Magnetic bimerons, which can be
found in various magnets [10, 35, 37, 38, 43, 45, 48–
50, 52], also has the potential to be used as information car-
riers for spintronic devices made of in-plane magnetized thin
films [10, 43, 45]. Recent studies on bimerons [43, 45, 47–
50, 52] focus on its dynamics induced by electric currents.
However, an electric current faces the issue of Joule heating
and is not applicable for insulating materials. Therefore, it is
necessary to explore alternative methods for manipulating FM
bimerons effectively.

In this work, we report the dynamics of FM bimerons in-
duced by spin currents and magnetic fields. We numerically
realize the simultaneous creation of two bimerons with op-
posite topological numbers via current-induced spin torques, and
we theoretically prove that such two bimerons can coexist in
a FM film with interfacial DMI. Our results show that in ad-
dition to the spin current, a magnetic field gradient can drive
a FM bimeron to motion. Furthermore, excited by alternating
magnetic field, the bimeron propagates along a certain direc-
tion, which does not show the skyrmion Hall effect when a
suitable magnetic field gradient is further adopted.

II. MODEL AND SIMULATION

Considering a FM film with perpendicular magnetic
anisotropy [Fig. 1(a)], the skyrmion [Fig. 1(d)] can be sta-
bilized by introducing the isotropic interfacial DMI [60, 61],
where the DMI can be induced at the ferromagnet/heavy metal
(such as Ta and Pt) interface. Here we focus on the study of
a FM film with in-plane easy-axis anisotropy [Fig. 1(b)].
In such a FM system, the asymmetrical bimeron [Fig. 1(e)]
is formed when the isotropic interfacial DMI is adopted. We
employ the Landau-Lifshitz-Gilbert (LLG) equation [63] with
the damping-like spin torque to simulate the dynamics of FM
systems, which is described as

\[
\dot{m} = -\gamma m \times H_{\text{eff}} + \alpha m \times \dot{m} + \gamma H_{\text{z}} m \times p \times m. \tag{1}
\]
\( \mathbf{m} \) (= \( \mathbf{M}/M_S \) with saturation magnetization \( M_S \)) is the reduced magnetization and \( \dot{\mathbf{m}} \) denotes the partial derivative of the magnetization with respect to time. The damping-like spin torque \( \gamma H_j \mathbf{m} \times \mathbf{p} \times \mathbf{m} \) can be produced by injecting a current into a magnetic tunnel junction or using the spin Hall effect. \( \mathbf{p} \) is the polarization vector and \( H_j \) relates to the applied current density \( j \), defined as \( H_j = j \hbar \theta_{SH}/(2\mu_0 e M_ST_z) \) with the reduced Planck constant \( \hbar \), the spin Hall angle \( \theta_{SH} \), the vacuum permeability constant \( \mu_0 \), the elementary charge \( e \), and the layer thickness \( t_z \). \( \gamma \) and \( \alpha \) denote the gyromagnetic ratio and the damping constant respectively. \( H_{\text{eff}} \) stands for the effective field obtained from the variation of the FM energy \( E \),

\[
E = \int dV \left\{ A (\nabla \mathbf{m})^2 - K (\mathbf{m} \cdot \mathbf{n})^2 - \mu_0 M_S \mathbf{H} \cdot \mathbf{m} \right. \\
+ \left. D [m_z \nabla \cdot \mathbf{m} - (\mathbf{m} \cdot \nabla)m_z] \right\}, \tag{2}
\]

where the first, second, third and fourth terms represent the exchange energy, magnetic anisotropy energy, Zeeman energy and DMI energy respectively. In Eq. (2), \( A \), \( K \) and \( D \) are the exchange constant, magnetic anisotropy constant and DMI constant respectively. \( \mathbf{n} = e_z \) stands for the direction of the anisotropy axis, and \( \mathbf{H} \) is the applied magnetic field. Note that the thermal fluctuation and dipole-dipole interaction are not taken into account.

To obtain the bimeron mentioned above, the presence of in-plane magnetic anisotropy in materials (such as CoFeB [62]) is essential. On the other hand, the out-of-plane spin configurations exist in the bimeron, and they will increase the system energy if the in-plane anisotropy is considered. By introducing other energies, such as the DMI energy, which leads to spin canting, the energy increase due to the anisotropy can be compensated, so that the bimeron can be formed in a FM film with DMI and in-plane easy-axis anisotropy (the stability diagram of the bimeron is shown in Fig. 9). Similar to DMI, the frustrated exchange interaction can also bring the spin canting [43], so that the bimeron can be stabilized in frustrated FM systems [49]. In addition to ferromagnets, the bimeron is a stable solution in antiferromagnets in the presence of DMI and in-plane anisotropy [48, 52]. Note that the shape of bimerons depends on the DMI. Taking isotropic DMI (see Fig. 1), i.e., the DMI vectors are in-plane and DMI energy constant \( D_x = D_y \), the formed bimeron has asymmetrical shape [52]. If we rotate the DMI vectors by \( 90° \) [see Fig. 1(c)] [43], the bimeron shape will be symmetrical [see Fig. 1(f)] [48]. The dynamics of symmetrical and asymmetrical FM bimerons induced by alternating magnetic fields will be discussed later, while for the bimeron in antiferromagnet, it is difficult to excite its dynamics by a magnetic field.

### III. Spin Current-Induced Creation of Bimerons

Creating bimerons is the foundation for their practical applications. Here we use a spin current to create the bimerons via damping-like spin torques. As shown in Fig. 2(a), the initial state is the FM ground state. When the current pulse of \( j = 1500 \text{ MA/cm}^2 \) and \( \mathbf{p} = e_z \) is injected into the central circular region with diameter of 30 nm, the magnetization in the circular region will be flipped towards the direction of the polarization vector \( \mathbf{p} \), as shown in Fig. 2(b). At \( t = 0.2 \text{ ns} \) [Fig. 2(d)], the current is switched off, and then the magnetic texture is relaxed [see Figs. 2(e)-(h)]. Figure 2(h) shows that after the relaxation, two bimerons are simultaneously generated. In addition, we calculate the time evolution of the topological number \( Q = -1/(4\pi) \int dxdy [\mathbf{m} \cdot \mathbf{H}_{\text{eff}} \times \nabla \mathbf{m}] \).
(∂ₚ × ∂ₚ m) [28, 35, 64], showing that for the two bimerons created here, the sum of their topological numbers equals to zero [see Fig. 2(i)]. This indicates their opposite topological numbers, which is also confirmed in Fig. 2(b). A pair of bimerons with opposite Q shown in Fig. 2(h) can be separated into two independent bimerons when a suitable spin current is applied, as they have opposite drift directions (see Fig. 4).

Note that an isolated bimeron with positive Q will be created when \( j = +1000 \) MA/cm², as shown in Fig. 10. If the sign of current is changed, i.e., \( j = -1000 \) MA/cm², the created bimeron has negative Q.

In order to analyze such a phenomenon, i.e., two bimerons with opposite signs of Q are stabilized in a FM film with the same background (see Video 1), [45, 47] we present the components \( m_x \) and \( m_y \) of the magnetization for the case of Fig. 2(h), as shown in Fig. 3. Figures 2(h) and 3 suggest that by using the operation \( |m_x(x, y), m_y(x, y), m_z(x, y)| \rightarrow |m_x(-x, y), -m_y(-x, y), -m_z(-x, y)| \), two bimerons created here can convert to each other. On the other hand, the operation mentioned above will affect the spatial derivative of the magnetization, \( (\partial_x, \partial_y) \rightarrow (-\partial_x, \partial_y) \). Thus, we obtain the operation for the spatial derivative of the magnetization, \( (\partial_x m_x, \partial_x m_y, \partial_x m_z) \rightarrow (-\partial_x m_x, \partial_x m_y, \partial_x m_z) \) and \( (\partial_y m_x, \partial_y m_y, \partial_y m_z) \rightarrow (\partial_y m_x, -\partial_y m_y, -\partial_y m_z) \). Taking the above operation and combining Eq. (2), it is found that the system energy E is not changed, however giving rise to a change in the sign of the topological number Q. As a result, the bimerons with opposite signs of Q can coexist in the FM film with in-plane anisotropy and isotropic DMI (see Fig. 1), while in a FM system with perpendicular magnetic anisotropy and isotropic DMI, the coexistence of different skyrmions with opposite topological numbers is not allowed. We note that taking the same values of parameters, the asymmetrical bimerons have a smaller size compared to the skyrmions.

**IV. SPIN CURRENT-DRIVEN MOTION OF BIMERONS**

In addition to creating the bimerons, manipulating them is also indispensable for the application of information storage and logic devices. We now use the spin current (instead of electric current) to manipulate the bimerons. Taking the current density \( j = 5 \) MA/cm² and the damping \( \alpha = 0.5 \), the time evolution of the velocities \( (v_x, v_y) \) for bimerons with opposite signs of Q is shown in Figs. 4(a)-(f), where the velocity \( v_i = \dot{r}_i \) and the guiding center \( (r_x, r_y) \) of the bimeron is defined as [17]

\[
\dot{r}_i = \frac{dx dy [m \cdot (\partial_x m \times \partial_y m)]}{\int dx dy [m \cdot (\partial_x m \times \partial_y m)]}, \quad i = x, y.
\]

From Fig. 4, we can see that for the cases where the polarization vector \( p = e_x, e_y \) and \( e_z \), the bimerons can be driven to motion and the velocity reaches a constant value at \( t = 0.2 \) ns. For the bimerons with opposite signs of Q, a spin current drives them to drift in the opposite directions. Namely, their skyrmion Hall angles \( \pm \arctan(v_y/v_x) \) have opposite signs. The above result means that two-lane racetracks (or double-bit racetracks) can be built in order to accurately encode the data bits, where the presence of a bimeron in the top and bottom lanes is used to encode the data bits “1” and “0” respectively. [47, 65–67] Compared to the single-lane racetrack based on skyrmions, such a two-lane racetrack based on bimerons is robust for the data representation, as we always detect a bimeron for the data bits “1” and “0”. In the single-lane racetrack, the data bits “1” and “0” are encoded by the presence and absence of a skyrmion respectively. However, the distance between two skyrmions may be affected by many factors, so that the number of the data bit “0” cannot be accu-
motion speed, spin torque is considered. From Eq. (4), we obtain the steady motion speed, and find that the velocity of the bimeron induced by magnetic fields. In the next sections, we focus on the study of the bimeron dynamics induced by magnetic field gradients and alternating magnetic fields. Figure 5(a) shows the time evolution of the velocities \((v_x, v_y)\) for the symmetric bimeron with positive \(Q\), where a magnetic field gradient \(H = \mu_0 dH/dx = 1 \text{ mT/mm}\) is applied and the damping \(\alpha = 0.5\). The change of bimeron size induced by the magnetic field can be ignored, and the velocities \((v_x, v_y)\) at \(t = 0.2\) ns almost reach a constant value of \(0.518 \text{ m/s}, 1.002 \text{ m/s}\). Figure 5(b) shows the velocities of the bimeron are proportional to the magnetic field gradient. Due to the presence of the magnetic field gradient, the potential energy of the system changes spatially, so that a nonzero driving force will act on the FM bimeron. We now derive the formula of the driving force induced by the magnetic field with a constant gradient. Applying a partial integration, [17] the induced force is derived from 

\[
F_{\text{grad}} = \mu_0 M s t_z u_H \frac{dH}{dx} e_x, \tag{6}
\]

where \(u_H = \int (1 - m_z) dx dy\) is 94.4 nm² for the parameters used here (see Fig. 12). Substituting the above Eq. (6) into Eq. (5), we obtain the steady motion speed, and find that the bimeron moves towards the area of lower magnetic field, similar to the case of the skyrmion [18]. As shown in Fig. 5(b), the results given by Eqs. (5) and (6) are consistent with the numerical simulations.

**V. MOTION OF BIMERONS DRIVEN BY MAGNETIC FIELD GRADIENTS**

Using the magnetic field as a driving source is applicable in both metals and insulating materials, so it is an important manipulation method, and it is necessary to discuss the dynamics of bimeron induced by magnetic fields. In the next sections, we focus on the study of the bimeron dynamics induced by magnetic field gradients and alternating magnetic fields. Figure 5(a) shows the time evolution of the velocities \((v_x, v_y)\) for the bimeron with positive \(Q\), where a magnetic field gradient \(H = \mu_0 dH/dx = 1 \text{ mT/mm}\) is applied and the damping \(\alpha = 0.5\). For the case shown in Fig. 5(a), the change of bimeron size induced by the magnetic field can be ignored, and the velocities \((v_x, v_y)\) at \(t = 0.2\) ns almost reach a constant value of \(0.518 \text{ m/s}, 1.002 \text{ m/s}\). Figure 5(b) shows the velocities of the bimeron are proportional to the magnetic field gradient. Due to the presence of the magnetic field gradient, the potential energy of the system changes spatially, so that a nonzero driving force will act on the FM bimeron. We now derive the formula of the driving force induced by the magnetic field with a constant gradient. Applying a partial integration, [17] the induced force is derived from 

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VI. MOTION OF BIMERONS DRIVEN BY ALTERNATING MAGNETIC FIELDS

Recently, an interesting method for manipulating magnetic skyrmions, was proposed, i.e., by using an oscillating electric field and combining a static magnetic field, where the electric field can modify the magnetic anisotropy. [73, 74] Such a method is applicable in both metals and insulators. With the oscillating electric field alone, the skyrmion will exhibit the breathing motion (rather than propagation along a certain direction) and the spin wave excitation is symmetric. When an in-plane static magnetic field is applied, the symmetry of the skyrmion is broken and then the spin wave excitation becomes asymmetric, resulting in nonzero net driving force. [73, 74] Thus, an oscillating electric field can drive the asymmetrical skyrmion to move along a certain direction. In addition, the skyrmion speed reaches its maximum value when the frequency of the oscillating electric field matches the eigenfrequency of the system. [73]

The bimerons studied here have intrinsic asymmetrical structure, so that they can be driven by the alternating field. Figures 6(a) and (b) show the trajectories of asymmetrical bimerons driven by an alternating magnetic field \( H = H_0 \sin(2\pi ft)\hat{e}_x \), where the applied magnetic field is uniform in space. Indeed, the propagation of asymmetrical bimerons are induced, and for the bimerons with opposite signs of \( Q \), their trajectories are essentially the same, except for their motion directions. For the purpose of comparison, we also calculate the motion of the symmetrical bimeron under the same magnetic field, as shown in Fig. 6(c), from which we can see that an alternating magnetic field cannot induce the symmetrical bimeron to propagation. Note that in addition to the alternating magnetic field, the alternating anisotropy can also excite the asymmetrical bimeron to move along a certain direction, as shown in Fig. 13.

On the other hand, based on the time evolution of the guiding center \( (r_x, r_y) \), the propagation velocities \( (v_x, v_y) \) of the bimeron can be obtained [see Fig. 6(d)]. Figures 7(a) and (b) show the velocities as functions of the frequency \( f \), where we take the alternating magnetic field \( H = H_0 \sin(2\pi ft)\hat{e}_x \) with amplitude \( \mu_0 H_0 \) of 10 mT and frequency \( f \) of 8 ~ 32 GHz. Similar to the case of the skyrmion, [73] the bimeron reaches its maximum speed when the frequency of alternating magnetic fields coincides with the system eigenfrequency of \( \sim 20.6 \) GHz [see the inset in Fig. 7(a)]. In addition, the velocities \( (v_x, v_y) \) are calculated as functions of the damping \( \alpha \), as shown in Figs. 7(c) and (d), where the alternating magnetic field has the amplitude of 10 mT and frequency of 20 GHz. To understand the results of the numerical simulations, we try to find the net driving force induced by the alternating magnetic field. As shown in the inset of Fig. 7(d), the ratio \( v_y/v_x \) obtained from numerical simulations can be described by \( \alpha \alpha_{dx}/(-4\pi Q) \). Thus, Eq. (5) suggests that the net driving force \( F_{\text{net}} \) is almost along the \( y \) direction. Assumed that \( F_{\text{net}} = c_1/\alpha + c_2 + c_3 \alpha + c_4 \alpha^2 \) with \( c_1 = 0.865 \times 10^{-16} \) N, \( c_2 = 1.398 \times 10^{-16} \) N, \( c_3 = -5.081 \times 10^{-16} \) N and \( c_4 = 4.975 \times 10^{-16} \) N, the results given by Eq. (5) agree with the numerical simulations, as shown in Figs. 7(c) and (d). It is worth mentioning that the bimeron will annihilate, when a strong alternating magnetic field (its amplitude and frequency are 100 mT and 20 GHz respectively) is applied (see Video 2).

VII. MAGNETIC BIMERONS SHOWING NO SKYRMION HALL EFFECT

As shown in Figs. 6 and 7, under the action of the alternating magnetic field, the FM bimerons show the skyrmion Hall effect due to the presence of the Magnus force \( (G \times v) \), and the motion speed is small (< 0.1 m/s). Here we introduce a force induced by magnetic field gradients to compensate the Magnus force, and then achieve this purpose of overcoming or suppressing the skyrmion Hall effect, as shown in Fig. 8(a), where the direction of the net driving force \( F_{\text{net}} \) (the \( y \) direction) is parallel to the racetrack. Figure 8(b) shows that as the magnetic field gradient \( \mu_0 dH/dx \) increases, the bimeron moves faster and the skyrmion Hall effect is effectively suppressed. When \( \mu_0 dH/dx \) increases to 0.28 mT/nm, the bimeron propagates parallel to the racetrack with the speed of \( \sim 0.374 \) m/s, so that the bimeron will not be destroyed by touching the racetrack edge. On the other hand, for the case of \( \mu_0 dH/dx = 0.28 \) mT/nm, the propagation of the bimeron is perpendicular to the gradient direction, so that the bimeron size is not affected by the space-dependent magnetic field. If \( \mu_0 dH/dx > 0.28 \) mT/nm, the force \( F_{\text{grad}} \) induced by the magnetic field gradient is larger than the Magnus force \( (G \times v) \), causing that
the bimeron moves towards the area of lower magnetic field [see Fig. 8(b)].

By changing the magnetic field gradient \( \mu_0 dH/dx \), the different velocities are obtained by numerical simulations, as shown in Figs. 8(c) and (d). In our simulations, the damping \( \alpha = 0.1 \), the frequency \( f \) of alternating magnetic fields is 20 GHz, and the amplitudes \( \mu_0 H_0 \) of 10 and 20 mT are adopted. Combining the Eq. (6) and substituting \( F_{\text{net}} = F_{\text{grad}} - F_{\text{net}} \) into Eq. (5), the analytical velocities are given. As shown in Figs. 8(c) and (d), the results given by Eq. (5) are consistent with numerical simulations, where the values of \( F_{\text{net}} \sim 9.58 \times 10^{-10} \) and \( 32.59 \times 10^{-16} \) N have been used for the cases of \( \mu_0 H_0 = 10 \) and 20 mT respectively. We now derive the critical magnetic field gradient, at which the bimeron moves without showing the skyrmion Hall effect, i.e., \( v_x = 0 \). Based on \( G \times v_y e_y + F_{\text{grad}} = 0 \), the critical magnetic field gradient is derived, which satisfies the following formula,

\[
\frac{dH}{dx} = \frac{4\pi Q}{\gamma u_H} v_y,
\]

where \( v_y = \gamma F_{\text{net}} / (\alpha d_{\mu_0} \mu_0 M_s t_x) \). As mentioned earlier, for the case of \( \mu_0 H_0 = 10 \) mT, our numerical simulation shows that the critical magnetic field gradient is \( \sim 0.28 \) mT/nm and the corresponding speed \( v_y \) is \( \sim 0.374 \) m/s. If the amplitude \( \mu_0 H_0 \) of the alternating magnetic field is increased to 20 mT, the critical magnetic field gradient and corresponding speed \( v_y \) are \( \sim 1.11 \) mT/nm and 1.486 m/s, respectively, as shown in Figs. 8(c) and (d). The above values obtained from numerical simulations obey Eq. (7).

VIII. CONCLUSIONS

In conclusion, we analytically and numerically study the dynamics of FM bimerons induced by spin currents and magnetic fields. Numerical simulations show that two bimerons with opposite signs of the topological numbers can coexist and have opposite drift directions. Our results are useful for understanding of the bimeron dynamics and may provide effective ways for building bimeron-based spintronic devices.

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Appendix A: Stability diagram of the FM bimeron

Figure 9 shows the stability diagram of the ferromagnetic bimeron for different values of $D$ and $K$, which is obtained by relaxing a bimeron with damping $\alpha = 0.1$ and simulation time $t = 5$ ns. In order to stabilize the bimeron, for a strong magnetic anisotropy $K$, a large DMI constant $D$ has to be introduced. In Fig. 9, the stable bimerons with negative $Q$ are shown. As discussed in the main text, the bimerons with opposite $Q$ can coexist in the FM systems, so that the bimeron with positive $Q$ can also be stabilized if the bimeron with negative $Q$ is a stable solution.

![Stability diagram of the FM bimeron](image)

FIG. 9. The stability diagram of the ferromagnetic bimeron for different values of $D$ and $K$, where the damping constant is 0.1 and other parameters are the same as those of Fig. 2. The color represents the out-of-plane component of magnetization and the empty area indicates that the relaxation state is the FM ground state.

Appendix B: Creation of the isolated bimeron

Figure 10 shows that when the current of $j = +1000$ MA/cm$^2$ is adopted, an isolated bimeron with positive sign of $Q$ is created, while the created bimeron has negative sign of $Q$ for $j = -1000$ MA/cm$^2$. Interestingly, the shape of magnetic structures excited by $j = +1000$ and $-1000$ MA/cm$^2$ has mirror symmetry at the same time.

![Time evolution of magnetization $m_z$](image)

FIG. 10. The time evolution of the magnetization $m_z$, where the currents of $j = +1000$ MA/cm$^2$ and $-1000$ MA/cm$^2$ are adopted, and other parameters are the same as those of Fig. 2.

Appendix C: The numerical values of $d$, $u$ and $u_{\text{H}}$ for the FM bimeron

In addition to the velocity of the FM bimeron, the time evolution of $d_{ij}$ and $u$ can be obtained by solving Landau-Lifshitz-Gilbert equation and combining their definitions. As shown in Fig. 11, $d_{xx} \sim 15.44$, $d_{yy} \sim 12.93$, and $d_{xy} \sim 0$ at $t = 0.2$ ns. In addition, for $p = e_{x}$, $e_{y}$ and $e_{z}$, $(u_{xx}, u_{yy})$ equals to $(0, -13.18 \, \text{nm})$, $(33.03 \, \text{nm}, 0)$ and $(0, 25.91 \, \text{nm})$, respectively, where the adopted parameters are the same as those of Fig. 4.

Figure 12 shows that the value of $u_{\text{H}}$ is $\sim 94.4 \, \text{nm}^2$ at $t = 0.2$ ns, where the adopted parameters are the same as those of Fig. 5(a).

![Time evolution of $u_{\text{H}}$](image)

FIG. 12. The time evolution of $u_{\text{H}}$, where the adopted parameters are the same as those of Fig. 5(a).

Appendix D: Motion of the asymmetrical bimeron induced by an alternating magnetic anisotropy

Figure 13 shows that similar to the case of the alternating magnetic field, an alternating magnetic anisotropy, i.e., $K = 0.8 \, \text{MJ/m}^3 + 0.02 \, \text{MJ/m}^3 \sin(2\pi ft)$ with $f = 10$ GHz, can induce the propagation of the asymmetrical bimeron. The alternating magnetic anisotropy could be realized by applying AC electric field or AC stress to material systems. [24]
FIG. 13. (a) The time evolution of the anisotropy constant $K$. (b) The trajectory of the asymmetrical bimeron with positive $Q$. (c) and (d) The time evolution of the guiding center $(r_x, r_y)$. Only the alternating magnetic anisotropy is adopted as the driving source. $\alpha = 0.5$ and other parameters are the same as those of Fig. 2.

Appendix E: Videos for the FM bimeron

Two videos are attached. Video 1 presents the creation of two FM bimerons via a spin-polarized current. Video 2 shows that the FM bimeron will annihilate when an alternating magnetic field $H = H_0 \sin(2\pi ft)e_x$ with $f = 20$ GHz and $\mu_0 H_0 = 100$ mT is applied.

Video 1. Creation of two FM bimerons via a spin-polarized current. The adopted parameters are the same as those of Fig. 2.

Video 2. An isolated bimeron is erased by applying an alternating magnetic field $H = H_0 \sin(2\pi ft)e_x$ with $f = 20$ GHz and $\mu_0 H_0 = 100$ mT, where $\alpha = 0.1$ and other parameters are the same as those of Fig. 2.
