



# Article Controllable Fabrication of SiC@C-Fe<sub>3</sub>O<sub>4</sub> Hybrids and Their Excellent Electromagnetic Absorption Properties

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**Abstract:** In this work, a batch of novel ternary hybrids (SiC@C-Fe<sub>3</sub>O<sub>4</sub>), characterized by SiC nanowires core, carbon shell, and adhered Fe<sub>3</sub>O<sub>4</sub> nanoparticles were controllably synthesized via surface carbonization of SiC<sub>nw</sub> followed by hydrothermal reaction. Carbon, which was derived from SiC with nanometer thickness, possesses an amorphous structure, while Fe<sub>3</sub>O<sub>4</sub> nanoparticles are in a crystalline state. Simultaneously, the inducement of Fe<sub>3</sub>O<sub>4</sub> nanoparticles can provide significant magnetic loss, which is well-tuned by changing the molar content of iron precursors (FeCl<sub>3</sub>·6H<sub>2</sub>O and FeCl<sub>2</sub>·4H<sub>2</sub>O). SiC@C-Fe<sub>3</sub>O<sub>4</sub> hybrids show great electromagnetic absorption performance owing to the synergy effect of dielectric and magnetic losses. The minimum refection loss can reach to -63.71 dB at 11.20 GHz with a thickness of 3.10 mm, while the broad effective absorption bandwidth (EAB) can reach to 7.48 GHz in range of 10.52–18.00 GHz with a thickness of 2.63 mm. Moreover, the EAB can also cover the whole X band and Ku band. The outstanding performance of the obtained material implys that it is a promising candidate as an electromagnetic absorber.

Keywords: SiC nanowires; carbon shell; Fe<sub>3</sub>O<sub>4</sub>; dielectric; magnetic; electromagnetic absorption

# 1. Introduction

Electromagnetic (EM) waves have played an increasingly important role in many fields, which provide plenty of convenience to our daily lives. However, it is also identified that EM waves can potentially threaten human health in different forms. To address this issue, many efforts were made toward exploring EM absorption materials, which are supposed to possess multiple features, including thin thickness, lightweight, wide bandwidth, strong absorption, and good environmental adaptability [1–3]. Undoubtedly, it is still a huge challenge for researchers to achieve this aim unless a suitable component and appropriate microstructure are designed for EM absorption materials.

Among various EM absorption materials, silicon carbide (SiC) owns unique and impressive properties (especially for its strong workability in harsh environment conditions) and has attracted much attention in recent decades [4–8]. However, ordinary SiC is not suitable for EM absorption due to its poor dielectric behavior, which can be effectively improved by changing its morphology in the nanoscale [9–12] or blending with relatively higher dielectric materials (e.g., CNTs [13], graphene [14], PPy [15]). The doping or decoration with heterogeneous metal (e.g., Fe [16], Ni [17], Co [18], Al [19], Cu [20]) or compound (Fe<sub>3</sub>O<sub>4</sub> [21], NiO [22], ZnO [23], HfC [24]) is another effective method for obtaining SiC-based absorbers. Generally, SiC-based EA materials with multiple features are designed and supposed to exhibit a more impressive performance, and consists of complicated microstructure and components at the same time. Liang et al. fabricated one dimensional SiC-Fe<sub>3</sub>O<sub>4</sub> nano hybrids by adopting a convenient polyol technique [21]. Fe<sub>3</sub>O<sub>4</sub> nanoparticles were used to modify SiC nanowires (SiC<sub>nw</sub>) in situ, which led to



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**Copyright:** © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https:// creativecommons.org/licenses/by/ 4.0/). a significant improvement for EM absorption. The reported minimum reflection loss (RL<sub>min</sub>) was 51 dB at 8.6 GHz. Wu et al. synthesized one-dimensional SiC<sub>nw</sub> decorated with ZnO nanoparticles and obtained a broad EAB of 6.60 GHz in range of 11.08 GH<sub>Z</sub> to 17.68 GHz [23]. Except for the predominant binary hybrids, some SiC-based ternary hybrids were also investigated. Guo et al. fabricated carbon-coated Co-SiC nanomaterials (Carbon-Co-SiC) through pyrolyzing methane on nanostructured Co<sub>3</sub>O<sub>4</sub>-SiC hybrids, whose RL values below 10 dB nearly covered the whole X or Ku band [25]. To enhance the EM absorption performance of SiC<sub>nw</sub>, Zhou and his group [26] obtained SiC@SiO<sub>2</sub>@Fe<sub>3</sub>O<sub>4</sub> hybrids using carbothermal reduction and a convenient polyol technique, in which silanol-groups-decorated SiO<sub>2</sub> nanoshells (approximately 2 nm in thickness) played an important role in the growing of Fe<sub>3</sub>O<sub>4</sub> nanoparticles by changing the weak hydrophilicity of SiC. However, their performances as ideal EA absorbers were still far from satisfying.

In this paper, a batch of novel ternary hybrids, characterized by SiC<sub>nw</sub> core, carbonshell, and adhered Fe<sub>3</sub>O<sub>4</sub> nanoparticles (SiC@C-Fe<sub>3</sub>O<sub>4</sub>), were fabricated via surface carbonization of SiC<sub>nw</sub> followed by hydrothermal reaction. The inducement of Fe<sub>3</sub>O<sub>4</sub> nanoparticles can provide significant magnetic loss, which is well-tuned by changing the molar content of iron precursors (FeCl<sub>3</sub>·6H<sub>2</sub>O and FeCl<sub>2</sub>·4H<sub>2</sub>O), leading to an excellent EM absorption performance during the microwave band of 2–18 GHz. In addition, the mechanism of this enhancement is discussed.

#### 2. Experimental Section

#### 2.1. Pristine Materials and Fabrication of SiC@C Nanowires

The pristine SiC<sub>nw</sub> materials (Diameter: 100~600 nm; Length: >100  $\mu$ m; Density: 3.21 g/cm<sup>3</sup>; Purity: ~98%) were purchased from XF Nano Materials Tech Co., Ltd. (Nanjing, China), whose chemical composition detected by X-ray spectrometer (EDS) technique is shown in Table S1. For the carbon-coated SiC nanowires (SiC@C), the specific synthesis process, detailed characteristics and EM absorption performances were described in our previous work [27]. However, it is noted that the furnace body condition is fixed to the temperature of 800 °C for 1h during surface carbonization of SiC<sub>nw</sub>.

#### 2.2. Fabrication of SiC@C-Fe<sub>3</sub>O<sub>4</sub> Hybrids

An amount of 40mg SiC@C nanowires was added into 30 mL distilled water in an ultrasonic bath, followed by magnetic stirring to achieve a uniform suspension. Two iron precursors (FeCl<sub>3</sub>·6H<sub>2</sub>O, FeCl<sub>2</sub>·4H<sub>2</sub>O) with different molar contents (4 mmol/4 mmol, 2 mmol/2 mmol, 1 mmol/1 mmol), dissolved in distilled water, were added to the suspension with constant stirring, respectively. Then, we added NH<sub>3</sub>·H<sub>2</sub>O drop by drop, which aimed to obtain an alkaline environment of pH 9~10. Finally, the mixtures were transferred to a polytetrafluoroethylene hydrothermal reactor. The hydrothermal reaction condition in stove box was controlled at 180 °C with a dwelling time of 12 h. At last, the final products were obtained after filtering, washed with distilled water, and dried at 50 °C under vacuum. For convenience, we labeled these products as SCF4-4, SCF2-2, and SCF1-1, respectively, in which the number ratio of 4-4 indicates the 4 mmol/4 mmol molar content of FeCl<sub>3</sub>·6H<sub>2</sub>O and FeCl<sub>2</sub>·4H<sub>2</sub>O.

#### 2.3. Characterization and Measurement

Morphology for SCF materials was characterized through scanning electron microscope (SEM) and transmission electron microscopy (TEM) technique. TEM tests are operated with a FE-HRTEM, Tecnai G<sup>2</sup> F20UTwin, FEI microscope (FEI, Hillsboro, OR, USA) at 200 kV. SEM was performed on samples with no sputter coating and operated at 15 kV, and the energy dispersive X-ray spectrometer (EDS) was operated with an accelerating voltage of 20.0 kV. Crystalline analysis was managed by X-ray diffraction (XRD) and Raman technique, which were operated on Bruker D8 advance (Bruker, Billerica, MA, USA) and a Renishaw microspectrometer (532 nm, Renishaw, Wotton-under-Edge, UK), respectively. The relative complex permittivity ( $\varepsilon_r$ ) and permeability ( $\mu_r$ ) in 2–18 GHz were obtained through a vector network analyzer (N5242A PNA-X, Agilent, Santa Clara, CA, USA). The uniform mixture of SCF samples/wax was pressed into toroidal shaped compact (Diameter:  $D_{outer} = 7.00 \text{ mm}$ ,  $D_{inner} = 3.04 \text{ mm}$ ).

#### 3. Results and Discussion

For all SCF samples, several sharp diffraction peaks ( $35.6^{\circ}$ ,  $41.4^{\circ}$ ,  $60^{\circ}$ ,  $71.8^{\circ}$ , and  $75.5^{\circ}$ ) can be detected, which point to the lattice plane (111), (200), (220), (311) and (222) of  $\beta$ -SiC (Figure 1). Different from pristine SiC, there are several new peaks ( $30.1^{\circ}$ ,  $35.5^{\circ}$ ,  $43.1^{\circ}$ ,  $53.5^{\circ}$ ,  $57.0^{\circ}$ , and  $62.6^{\circ}$ ) for SCF samples. These peaks correspond to the lattice plane (220), (311), (400), (422), (511), and (440) of the magnetite Fe<sub>3</sub>O<sub>4</sub> phase (Cubic structure, PDF#88-0866), respectively. It is easy to find that the relative intensity of Fe<sub>3</sub>O<sub>4</sub> becomes more distinct with the increasing molar content of iron precursors (FeCl<sub>3</sub>·6H<sub>2</sub>O and FeCl<sub>2</sub>·4H<sub>2</sub>O). Moreover, a broad peak at 26.5°, corresponding to the (002) reflection of the carbon phase can also be detected for SCF samples, which is inferred as an amorphous carbon phase based on the previous work [27]. A similar phenomenon also occurs for some other carbon materials with solid crystalline characteristics or an amorphous solid state [28].



Figure 1. XRD spectra for all samples investigated.

Figure 2 shows that there are several Raman peaks for SCF samples, located at  $680 \text{ cm}^{-1}$ , 796 cm<sup>-1</sup>, 973 cm<sup>-1</sup>, ~1342 cm<sup>-1</sup>, and ~1600 cm<sup>-1</sup>. Therein, the peak at 680 cm<sup>-1</sup> points to the Fe<sub>3</sub>O<sub>4</sub> phase, whose intensity gradually increases as a function of molar content of iron precursor, further confirming that SiC@C-Fe<sub>3</sub>O<sub>4</sub> hybrids are successfully synthesized. Moreover, the 796 cm<sup>-1</sup> peak should be attributed to the signals of transversal of SiC, while the 973 cm<sup>-1</sup> peak to longitudinal optical phonons while tested. These two peaks for SCF samples are very weak or hard to detect owing to the special structures and complex compositions, which formed after all synthesis procedures. Simultaneously, the peaks at ~1342, ~1600 cm<sup>-1</sup> for all SCF samples are apparent and not shown in the pristine SiC<sub>nw</sub> sample. Based on our previous work, it is demonstrated that they are caused by the disordered D-mode and ordered G-mode of carbon, respectively [29–31]. This means the core–shell structure may be reserved well after the growing process (Figure S1) of metal oxide, which can be proven by microstructure observation.



Figure 2. Raman spectra for all samples investigated.

Figure 3 depicts TEM or HRTEM images taken from the final SiC@C-Fe<sub>3</sub>O<sub>4</sub> samples investigated. It can be seen that SCF samples are all composed of three parts, corresponding to SiC, carbon, and  $Fe_3O_4$  nanoparticles, respectively. Clearly, the hybrids are characterized by SiC core and a carbon shell, as well as the  $Fe_3O_4$  nanoparticles outside the carbon shell, which is in line with results of the SEM images (Figure S2). The increase in the molar content of iron precursor led to an increase in the loading density of Fe<sub>3</sub>O<sub>4</sub> nanoparticles on carbon (Figure 3a–c). The nanowires are composed by four elements (C, Si, O, Fe) from the line scanning profiles, as shown in Figure 3d, which is in line with the results by EDS technique (Table S1). Moreover, the C line is broader compared with the Si element, confirming the core-shell structure of SiC@C. Simultaneously, the Fe and O lines cover nearly all ranges with weak fluctuations, inferring that a large quantity of  $Fe_3O_4$  nanoparticles attach to the whole surface of SiC@C. Figure 3f shows the interface between SiC core and the carbon middle shell [27], and the interface between the carbon shell and Fe<sub>3</sub>O<sub>4</sub> nanoparticles. It is apparent that  $\beta$ -SiC and the Fe<sub>3</sub>O<sub>4</sub> phase possess crystal structures, featured with plane (111) and plane (311), respectively. The predominately amorphous carbon phase has a very important effect on the nucleation of Fe<sub>3</sub>O<sub>4</sub> nanoparticles, possibly owing to some groups (C–OH, COOH) on SiC@C that are helpful for the formation of the hydrogen band between carbon atoms and  $Fe_3O_4$  [32]. Differently, Liang et al. reported that the transitional silica layer between the SiC phase and Fe<sub>3</sub>O<sub>4</sub>, was decorated by Si–OH groups, which helped form  $Fe_3O_4$  nanoparticles [21]. Moreover, it is observed that the  $Fe_3O_4$ nanoparticles with a relatively homogeneous size of about 11 nm cluster in some degree and seem to be loose areas, which are possibly caused by the magnetic dipole-dipole attraction [32]. Additionally, this phenomenon is more clear as the molar content of iron precursor increases, which might lead to a decline in the synergy effect on attenuating EM waves.



**Figure 3.** TEM images of all samples investigated: (a) SCF1-1; (b) SCF2-2; (c) SCF4-4; Line scanning profiles (d) of C, Si, O, and Fe recorded along the line labeled in HRTEM image (e) of SCF1-1; HRTEM image (f) derived from the area M in (e).

To further study the magnetic character of the SCF samples, the field-dependent magnetization curves of SiC@C-Fe<sub>3</sub>O<sub>4</sub> samples were analyzed and drawn in Figure 4. The hybrids for SCF1-1, SCF2-2, SCF4-4 had magnetic saturation values of 36.9, 45.2, and 58.3 emu·g<sup>-1</sup>, respectively. Clearly, increasing the molar content of iron precursor accelerates the formation of Fe<sub>3</sub>O<sub>4</sub> nanoparticles on the surface of the carbon shell and helps to obtain a high level of magnetic saturation. Simultaneously, it can be inferred that the strategy used in this paper is feasible for adjusting the magnetic property by changing the molar content of iron precursors.



Figure 4. Room temperature field-dependent magnetization curves of SiC@C-Fe<sub>3</sub>O<sub>4</sub> hybrids.

The complex permittivity ( $\varepsilon_r = \varepsilon' - j\varepsilon''$ ), permeability ( $\mu_r = \mu' - j\mu''$ ) characterizations, as well as the corresponding dielectric tangent, magnetic tangent loss of different materials are shown in Figure S3. It is apparent that these materials show a similar frequency dependency. Nevertheless, both  $\varepsilon'$  and  $\varepsilon''$  of SCF samples have lower values

compared with SiC<sub>nw</sub> in the same condition, which should be explained by nature distinction of SiC and Fe<sub>3</sub>O<sub>4</sub>. SiC belongs to typical dielectric loss material for microwaves, while Fe<sub>3</sub>O<sub>4</sub> belongs to a magnetic material. In our previous work [27], it was found that the dielectric property of SiC<sub>nw</sub> was enhanced by surface carbonization, which led to the achievement of SiC@C. It is also inferred that the controllable inducement of magnetic Fe<sub>3</sub>O<sub>4</sub> nanoparticles may further change the dielectric properties [32,33]. It can be observed from Figure 5 that the magnetic tangent loss has a great increment for the SiC@C-Fe<sub>3</sub>O<sub>4</sub> hybrids in comparison with SiC<sub>nw</sub>, while the value of dielectric tangent loss for SiC<sub>nw</sub> and SCF samples stays at a similar level. However, the curves for the latter are more even than SiC. Moreover, it seems that increase the molar content of iron precursor cannot help to increase the dielectric tangent loss or magnetic tangent loss, inferring that a moderate molar proportion of iron precursor is needed to synthesize SiC@C-Fe<sub>3</sub>O<sub>4</sub> with good dielectric and magnetic properties for microwave absorption at the same time.



**Figure 5.** Dielectric (**a**) and magnetic (**b**) tangent loss values of  $SiC_{nw}/wax$  and SCF/wax over 2–18 GHz with the same loading of 40 wt%.

Figure 6 shows the reflection loss of the composites/wax versus frequency. Therein, the microwave absorption performance is simulated based on the transmission line theory. Undoubtedly, SCF1-1 has a higher level of EM absorption compared with other samples. The value of  $RL_{min}$  for SCF1-1 reaches -63.71 dB at 11.20 GHz at a thickness of 3.10 mm. Its effective absorption bandwidth (EAB) less than -10 dB can reach to 6.88 GHz (11.00– 17.88 GHz) with a thickness of 2.62 mm. Furthermore, the EAB of this sample can cover the X band and Ku band with thicknesses of 2.43 and 3.44 mm, respectively. However, the broadest EAB of 7.48 GHz (10.52-18.00 GHz) is achieved under a thickness of 2.63 mm when the loading of SCF1-1 decreases from 40 wt% to 30 wt% (Figure S4b). This phenomenon infers that the EM absorbing property could be further controlled by adjusting the loading of the absorbers. The value of  $RL_{min}$  for SCF2-2 and SCF4-4 can reach to -63.68 dB with a thickness of 3.86 mm when the loading is 40 wt%, and -61.12 dB with a thickness of 3.48 mm when the loading is 50wt% (Figure S4e), respectively. In conclusion, the value of RL<sub>min</sub> for SiC@C-Fe<sub>3</sub>O<sub>4</sub> is lower than SiC<sub>nw</sub> and SiC@C samples. Moreover, the EAB value (7.48 GHz) for SCF1-1 at a loading of 30 wt% is also broader. Compared with other microwave attenuation materials, such as SiC@Fe<sub>3</sub>O<sub>4</sub> [21], 3D Fe<sub>3</sub>O<sub>4</sub>-MWCNTs [33], the present materials exhibit a better behavior (lower RL<sub>min</sub> and broader EAB), demonstrating a successful strategy for microwave absorbers, as this paper details.



**Figure 6.** 3D-RL plots of the composites over 2–18 GHz at different thickness of 1–8 mm with the same loading of 40 wt.% ((a): SiC<sub>nw</sub>; (b): SCF1-1; (c): SCF2-2; (d): SCF4-4).

The possible enhancement mechanisms of EM absorption for the obtained final SiC@C- $Fe_3O_4$  hybrids are shown in Figure 7. In general, the synergy effect of dielectric and magnetic loss is a very important characteristic for excellent EM absorbers. When the input impedance of the EM absorbers reaches the impedance of free space, there is little reflection on the surface of the materials for the incident EM wave, which leads a strong attenuation of EM wave energy inside the materials, and a higher efficiency EM absorption. From this point, it is an efficient way to introduce magnetic loss to typical dielectric absorbers (Figure 7a). Without a doubt, a moderate proportion of  $Fe_3O_4$  in the final SiC@C-Fe\_3O\_4 materials and rational loading in SiC@C-Fe<sub>3</sub>O<sub>4</sub>/wax is needed to get close to the ideal balance of permeability and permittivity, as well as the impedance match of the materials. Generally, the magnetic loss can originate from exchange resonance, natural ferromagnetic resonance and the eddy current effect, etc. The scale of  $Fe_3O_4$  nanoparticles in this study is approximately 11 nm by measure (close to the exchange length), indicating the possible existence of exchange resonance. Figure S5 shows the frequency dependence of the C<sub>0</sub>  $(C_0 = \mu''(\mu')^{-2}f^{-1})$  of different SCF samples with 40% loading weights as well as the SCF1-1 sample with different loading weights, whose value is approximately constant when the frequency exceeds 15 GHz, which is likely contributed to by the eddy current effect [33].



**Figure 7.** Schematic diagram of EM absorption mechanism of SiC@C-Fe<sub>3</sub>O<sub>4</sub> hybrids ((**a**) Magnetic loss introduced by  $Fe_3O_4$  nanoparticles; (**b**) Multiple polarization between carbon shell and  $Fe_3O_4$  nanoparticles or SiC; (**c**) Conductive loss contributed almost by carbon; (**d**) Schematic diagram of energy dissipation among hybrids).

Moreover, the present SiC@C-Fe<sub>3</sub>O<sub>4</sub> hybrids have many other features which are also beneficial for attenuating EM waves. For example, the Fe<sub>3</sub>O<sub>4</sub> nanoparticles do not stick to the SiC<sub>nw</sub> directly. There is a middle layer, namely the carbon shell on the surface of SiC<sub>nw</sub>, which has a relatively better conductivity and helps to increase conductivity loss (Figure 7c) [34]. Moreover, the carbon shell between the SiC and Fe<sub>3</sub>O<sub>4</sub> phase possesses many pores (mesopores or macropores) demonstrated by previous work [27], implying that there are many defects that can cause the dipole polarization and Debye relaxations by breaking the balance of the charge distribution [35,36]. In addition, phase boundaries among the SiC<sub>nw</sub> core, the porous carbon shell, and the Fe<sub>3</sub>O<sub>4</sub> nanoparticles on the surface of carbon, possibly cause the surface charge redistribution and generate multiple interfacial polarization (Figure 7b). Furthermore, owing to the macro-porous characteristic of the SiC@C-Fe<sub>3</sub>O<sub>4</sub> hybrids derived from three-dimensional interlaced stacking in wax, more multiple reflections and scattering will be generated to attenuate or dissipate the EM wave energy (Figure 7d). Thus, the SiC@C-Fe<sub>3</sub>O<sub>4</sub> hybrids with core–shell microstructures can be regarded as an ideal EM absorber.

## 4. Conclusions

In conclusion, a novel and simple strategy for the controllable fabrication of SiC@C-Fe<sub>3</sub>O<sub>4</sub> hybrids via surface carbonization and hydrothermal reaction was raised. The microstructure, permeability, as well as permittivity of the final hybrids can be well adjusted by changing the molar content of the iron precursors (FeCl<sub>3</sub> $\cdot$ 6H<sub>2</sub>O and FeCl<sub>2</sub> $\cdot$ 4H<sub>2</sub>O). The nanoporous carbon shell should have an important effect on the nucleation of Fe<sub>3</sub>O<sub>4</sub> nanoparticles (with a small size of about 11 nm), possibly derived from the hydrogen band effect between the C atoms and the  $Fe_3O_4$  phase. This will also help to improve the homogeneity or quality of hybrids. However, the  $Fe_3O_4$  nanoparticles cluster can also be observed to some degree. This phenomenon is possibly caused by the magnetic dipole-dipole attraction, and easily occurs at a high molar content of the iron precursor. Thus, the moderate condition during synthesis is vital. Comparatively, SCF1-1 exhibits the best EM absorption performance among the final hybrids; its RL<sub>min</sub> can reach -63.71 dB and EAB can reach 7.48 GHz in the range of 10.52–18.00 GHz. The excellent EM absorption performance of the final hybrids can be attributed to their good synergy of dielectric loss (including conductive loss and polarization relaxations) and magnetic loss (introduced by magnetic Fe<sub>3</sub>O<sub>4</sub> nanoparticles), indicating a promising nanomaterial as an EM absorber.

**Supplementary Materials:** The following are available online at https://www.mdpi.com/article/10 .3390/nano11123438/s1, Figure S1: Schematic illustration for fabrication of SCF hybrids, Figure S2: SEM images of SiC<sub>nw</sub> and SCF1-1 sample, Figure S3: The complex permittivity and permeability characterizations of SiC<sub>nw</sub> and SCF samples with the same loading of 40 wt.%, Figure S4: 3D-RL plots of the SCF samples with other loading weights, Figure S5: Frequency dependence of the C<sub>0</sub> of the SCF samples with a loading weight of 40% (a) as well as the SCF1-1 sample with different loading weights (b), Table S1: Chemical compositions of pristine SiC<sub>nw</sub> and SCF hybrids.

**Author Contributions:** Conceptualization, L.D. and F.W.; methodology, L.D. and A.X.; software, J.-A.W.; validation, X.D., M.S. and Y.X.; formal analysis, L.D. and Y.X.; investigation, L.D.; resources, L.D.; data curation, J.-A.W. and M.S.; writing—original draft preparation, L.D.; writing—review and editing, L.D. and X.D.; visualization, L.D.; supervision, L.D.; project administration, L.D. and F.W; funding acquisition, L.D. and F.W. All authors have read and agreed to the published version of the manuscript.

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