4D Printing of Complex Structures with a Fast Response Time to Magnetic Stimulus

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1. Calculation of the Magnetic Force on a Model 3D Square Strip

As shown in Figure 2b, the non-uniform, external magnetic field intensity at position x of the square strip (H_x) could be calculated by Eq. (S1):

$$H_x = H_0 + H' \cdot x \qquad \text{(S1)}$$

where H_0 is the magnetic field intensity at the strip's top end, and H' is the magnetic field gradient constant. Thus, the external magnetic field induced magnetization intensity of Fe particle at position x of the square strip (M_x(Fe)) could be calculated by Eq. (S2):

$$M_x(Fe) = 0.028\,(H_0 + H' \cdot x)(\frac{emu}{Oe \cdot g}) \qquad \text{(S2)}$$

Because PDMS component in the PDMS/Fe composite ink is non-magnetic, the external magnetic field induced magnetization intensity of the ink at position x of the square strip (M_x) could be calculated by Eq. (S3):

$$M_x = 0.028\,(H_0 + H' \cdot x)\rho'(\frac{emu}{Oe \cdot cm^3}) \xrightarrow{(\frac{emu}{Oe \cdot cm^3})=4\pi} 0.112\pi\rho' \cdot (H_0 + H' \cdot x) \qquad \text{(S3)}$$

where ρ' (g/cm^3) is the equivalent density of Fe particle in the PDMS/Fe composite ink.

In a non-uniform, external magnetic field, the magnetic force acted on magnetic dipoles could be calculated by Eq. (S4): [1]

$$F = m\frac{\partial B_x}{\partial x} \qquad \text{(S4)}$$

where m is the magnetic dipoles' magnetic moments, and $\frac{\partial B_x}{\partial x}$ represents the gradient of magnetic flux density at position x. For the square strip with the cross section area of S, the magnetic dipoles' magnetic moments of a length of dx at position x could then be calculated by $M_x \cdot S \cdot d_x$. Thus, the magnetic force on it could be calculated by Eq. (S5):

$$dF =$$

$$M_x \cdot S \cdot d_x \frac{dB_x}{dx} \xRightarrow{(B_x=\mu H_x)} = \mu \cdot M_x \cdot S \cdot d_x \frac{dH_x}{dx} \xRightarrow{\frac{dH_x}{dx}=H'} = \mu \cdot M_x \cdot S \cdot d_x \cdot H' \xRightarrow{M_x = 0.112\pi\,(H_0 + H' \cdot x)\rho'} =$$

$$0.112\pi \cdot \mu(H_0 + H' \cdot x)\rho' \cdot S \cdot H' \cdot d_x \qquad \text{(S5)}$$

where μ is the relative magnetic permeability. μ could be calculated by Eq. (S6):

$$\mu = \mu_0(1 + X_m) \qquad \text{(S6)}$$

where μ_0 is the permeability of vacuum, and X_m is the magnetic susceptibility of the PDMS/Fe composite square strip. X_m could be further determined by Eq. (S7):

$$X_m = \frac{M}{H} = 0.112\pi\rho' \qquad \text{(S7)}$$

Thus, the magnetic force F_m on the whole square strip could be calculated by Eq. (S8):

$$F_m = \int_0^L dF = \int_0^L 0.112\pi \cdot \mu \cdot (H_0 + H' \cdot x)\rho' \cdot S \cdot H' d_x \xRightarrow{\mu=\mu_0(1+X_m)=\mu_0(1+0.112\pi\rho')}$$

$$= \mu_0(1 + 0.112\pi\rho')0.112\pi \cdot \rho' S H' \left(H_0 \cdot L + H' \cdot \frac{L^2}{2}\right) \qquad \text{(S8)}$$

2. THz Properties of 3D-TPC Samples

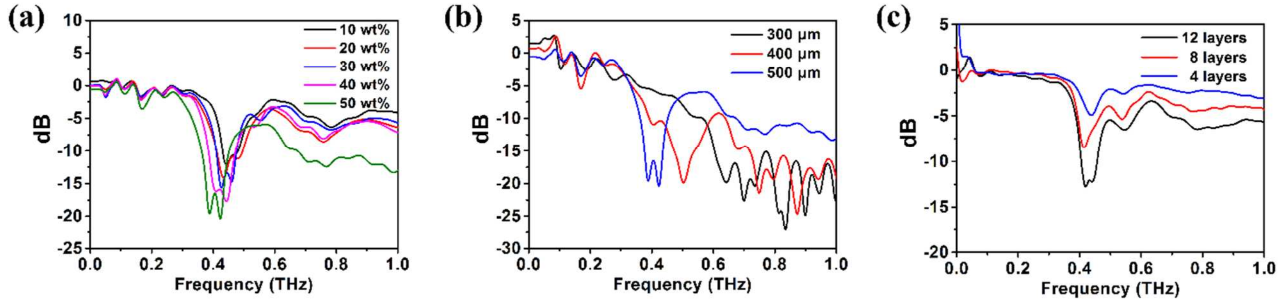

Figure S1 The transmission THz spectra of (a) 3D-TPCs created by the PDMS/Fe composite inks of different Fe particle contents (from 10 wt% to 50 wt%) with the same geometry (12-layers, D ~ 200 μm, w ~ 160 μm, and d ~ 500 μm), (b) 3D-TPCs created by the PDMS/Fe composite ink of 30 wt% Fe particle content with different rod spacing values of ~ 300 μm, 400 μm, and 500 μm (12-layers, D ~ 200 μm, w ~ 160 μm). (c) 3D-TPCs created by the PDMS/Fe composite ink of 50 wt% Fe particle content with 4, 8, and 12 layers (D ~ 200 μm, w ~ 160 μm, and d ~ 500 μm).