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Electric Field Control of Nonvolatile Four-state Magnetization at Room Temperature

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The control of magnetization by an electric field at room temperature remains as one of the great challenges in materials science. Multiferroics, in which magnetism and ferroelectricity coexist and couple to each other, could be the most plausible candidate to realize this long-sought capability. While recent intensive research on the multiferroics has made significant progress in sensitive, magnetic control of electric polarization, the electrical control of magnetization, the converse effect, has been observed only in a limited range far below room temperature. Here we demonstrate at room temperature the control of both electric polarization by a magnetic field and magnetization by an electric field in a magnetoelectric (ME) hexaferrite $Ba_{0.52}Sr_{2.48}Co_2Fe_{24}O_{41}$. The electric polarization in this compound rapidly increases in low magnetic fields (~5 millitesla), and its magnetoelectric susceptibility reaches the highest value (3200 ps/m) among single-phase materials. The magnetization is then modulated up to 0.62 μB/formula unit in an electric field of 1.14 MV/m. We find further that four ME states induced by different ME poling exhibit unique, nonvolatile magnetization versus electric field curves, which can be approximately described by an effective free energy with a distinct set of ME coefficients.