Abstract Submitted
for the MAS21 Meeting of
The American Physical Society

Multiple Ferroic Orders and Toroidal Magnetoelectricity in a Chiral Magnet $BaCoSiO_4$ XIANGHAN XU, FEI-TING HUANG, SANG-WOOK CHEONG, Rutgers University — $BaCoSiO_4$ adopts a $P6_3$ lattice at RT, which is structurally chiral and polar. The magnetic Co^{2+} ions form a triangular lattice, and an extremely intriguing toroidal moment plus canted ferromagnetic moment type magnetic structure appears below 3.2 K, which holds magnetic chirality as well. Our comprehensive electron microscopy study of high-quality $BaCoSiO_4$ single crystal grown by the Laser Floating Zone technique reveals a mono global chirality from the prototypic lattice, as well as various local chirality consisting of stripy polar domains and ferro-rotational domains. If the magnetic chirality is fixed by the structurally mono global chirality, applying magnetic field along c can create net toroidicity, and off-diagonal linear ME effect could be observed, and vice versa. The orientation-dependent ME effect is measured on oriented single crystals at 2 K. The data show that $BaCoSiO_4$ has both diagonal response $P_c(H_c)$ and off-diagonal response $P_{a*}(H_a)$. This off-diagonal response is consistent with the theoretical scenario that a toroidal moment along c axis with in-plane H induces in-plane P perpendicular to H. The observable toroidal ME effect suggests that the magnetic chirality is fixed by the structurally mono global chirality. The resulting mono magnetic chirality ensures the effective tuning of toroidal moment by field along c. "-3 to -1 to 1 to 3" toroidal moment metamagnetic transitions are demonstrated, and the induced P triples in a consistent manner. $BaCoSiO_4$ is a unique playground for studying the multifaceted coupling of structural and magnetic ferroic orders.

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Date submitted: 13 Nov 2021 Electronic form version 1.4