Multiferroic materials exhibit more than one primary ferroic ordering (ferromagnetism, -electricity, -vorticity or -crystallinity) in the same phase. The expression is extended to include non-ferroic orderings (antiferromagnetics) as well as ferroic composites.

BiFeO₃ (BFO) is a single phase multiferroic with rhombohedral distorted perovskite cells (R3c). Ferroelectric (below Tₘ ~ 830°C) and antiferromagnetic (AFM) G-type (below Tₘ ≈ 370°C) with weak ferromagnetism. Major drawbacks – relatively high leakage current – induced by Fe³⁺ to Fe²⁺ hopping through oxygen vacancies. Difficult to synthesis pure single-phase BFO – thermal stability of Fe³⁺ comparable to Fe³⁺ (susceptible perovskite phase). Extremely high coercive field – demands large bipolar switching. Realisation of a large polarization in bulk BFO still remains a challenge.

Structural distortions: Large displacement of B³⁺ (112) relative to the Fe³⁺ octahedra (interoctahedral Ni-B twelve point pair) – Spontaneous ferroelectric polarization (±112). Each Fe³⁺ spin is surrounded by six antiparallel spins on the nearest Fe³⁺ (G-type AFM). Magnetic moments/spins couple AFM (Neel) between neighboring and ferromagnetically within pseudocubic (111) planes.

**BiFeO₃ – based perovskite compounds**

- FeMnO₃/Fe₃O₄/CoFe₂O₄: Exchange bias effect.
- BiFeO₃: an important multiferroic material.

**AFM spin structure**

- AFM moments are perpendicular to the (111) – the symmetry: two ferromagnetic domains (Fe²⁺-Fe³⁺-Mg²⁺-Mn²⁺-Mg²⁺-Mn³⁺). AFM plane is always perpendicular to the Fe₂O₃ ferromagnetic domain (Jahn-Teller coupling).

**Spin properties**

- Spin-modulated 2D AFM spin is similar to the spontaneous, microscopic magnetisation.

**How to suppress the spin spin modulation?**

- Solid-state solutions: Alloy BiFeO₃ with other perovskite AB₂O₃ materials (forming pseudo-binary systems) such as Bi₂Fe₄O₁₀, Bi₃Fe₅O₁₀, or Bi₄Fe₈O₁₅.
- PTO₃, has tetragonal structure (Pmnm), very good ferroelectric, piezoelectric properties (P₂₀₀ mm, P₄₀₀ mm), and features chemically ordered micro-regions where spin spin modulation decreases.
- Helps in phase stabilisation, in strong magnetostrictive coupling (Γ₂⁻), and in achieving large tetragonality (20% near MBF).

**Electric field distribution**

- Without Cloak (a) With Cloak (b)

**Transformation Optics and Transformation Acoustics**

- Transformation optics and transformation acoustics are the mathematical tools that simplify the design and modelling of optical and acoustical devices by alternating the coordinate system.
- These techniques are drawn on a correspondence between coordinate transformation and materials parameters.
- Comply artificial materials known as Metamaterials are used to produce transformation in optical and acoustical space.

**Transformation Optics**

- In EM space, the magnetic field vector (B), the electric displacement vector (D) and Poynting vector (P) transform in a certain way in order to preserve the form of Maxwell’s equations.
- Therefore the Maxwell equation retains the same form under coordinate transformation. It is the successive value of permittivity and permeability that change over time.

**Transformation Acoustics**

- The same idea of transformation can be applied to acoustical devices. For instance, sound waves whose mass density tensor and bulk modulus are the associated parameter to coordinate transformation.
- Any manipulation of sound fields that can be described by a coordinate transformation can be realised through complex acoustical materials defined by the transformation itself.

**Experimental Realization of Bidirectional, Bandwidth Enhanced Metamaterial Absorber for Microwave Applications**

- Perfect absorber is a material which absorbs all the incident radiation at the operating frequency while minimizing the transmission and reflection.
- Metamaterials can be used to make EM absorber by engineering the complex permittivity and permeability.
- Advantages over the conventional absorbers as metamaterial absorbers can be polarization insensitive, wide angle receptive and have smaller size and less thickness.
- Design comprises of metal-dielectric-metal configuration with square and strips.
- Contrary to most of the metamaterial absorbers which use a complex metallic film on one side of the substrate, the proposed absorber utilises metallic patterns on both the sides enabling broadband absorption from both incident directions.
- The metallic patterns are made of copper with thickness of 0.03 mm and dielectric layer of FR-4 with a thickness of 0.1 mm and dielectric constant of 4.3.
- Optimised design gives Absorption, A=85.7

**Transformation Optics for Microwave Applications**

- Maxwell equations are form-invariant under coordinate transformation (CT) and the electromagnetic (em) waves follow the geometry of the medium are the prime facts based on which transformation electromagnetics (T-E) work.
- Using CT, the geometries of the spaces are distorted and the em wave flows through the distorted geometry.
- Electromagnetically speaking, the distorted geometric can be equated to a new medium with permittivity (ε) and permeability (μ) values different from those of the undistorted space.
- Devices such as cloaks, hyperlens, beam steerer, wavefront, field rotators, lenses like the flat lens, Luneberg lens, etc. are realised.
- In electromagnetics, the theoretically proposed devices are achieved using metamaterials (MMs) and photonic crystals (PhCs).

**Temporal Photonic Crystal (TPC)**

- Similar to temporal photonic crystal (TPC), unlike photonic crystals (PhC), have time dependent electrical permittivity (ε). The dynamic interface and bulk of a dielectric medium influence the reflection and transmission of incident electromagnetic wave (EMW).
- Similar to frequency gap or band gap in PC, we expect a gap in TPC.
- Reflection and transmitted EMW have not experienced frequency than that.
- Dynamical electrical permittivity system can produce pair of photons from vacuum states (analogous to Cauchy Effect).
- Self phase modulation of a plane EMV due to decreasing refractive index at. time exhibit circular effect like phenomenon.