Anjan Barman

Senior Professor

CMPMS

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Guidance of Students/Post-Docs/Scientists

a) Ph.D. Students

1. Avinash Kumar Chaurasiya; Brillouin Light Scattering Studies of Spin Waves in Ferromagnetic Thin Films and Nanostructures; Thesis submitted
2. Anulekha De; Ultrafast Spin Dynamics in Ferromagnetic Thin Films and Nanostructures; Thesis submitted; Prof. Rajib Kumar Mitra (Co-supervisor)
3. Sourav Sahoo; Ultrafast Spin Dynamics of 2D and 3D Magnonic Crystals; Under progress
4. Surya Narayan Panda; All-Optical Investigation of Spin-Orbit Effects in Ferromagnet/Nonmagnet Heterostructures; Under progress
5. Koustuv Dutta; Femto and Picosecond Spin Dynamics of Low Dimensional Magnetic Structures; Under progress
6. Amrit Kumar Mondal; Spin Wave Propagation and Localization in Continuous and Confined Magnetic Thin Film; Under progress
7. Arundhati Adhikari; Quasistatic and Ultrafast Magnetization Dynamics in Ferromagnetic Nanostructures; Under progress
8. Sudip Majumder; Ferromagnetic Resonance of Magnetic Thin films and Nanostructures; Under progress; Prof. Rajib Kumar Mitra (Co-supervisor)
9. Pratap Kumar Pal; Spin Dynamics in Ferromagnetic Thin Film and Nanostructures; Under progress
10. Sreya Pal; Spin Dynamics in Quantum Materials; Under progress
11. Soma Dutta; Ultrafast Magnetization Dynamics in Thin Film Heterostructures; Under progress
12. Suchetana Mukhopadhyay; Static and Dynamics Magnetic Properties of Topological Insulator/Ferromagnet Heterostructures; Under progress; Prof. Chiranjib Mitra, IISER Kolkata (Co-supervisor)
13. Santanu Pan; Ultrafast Spin Dynamics in Ferromagnetic Thin Films and Heterostructures; Awarded
14. Kartik Adhikari; Ferromagnetic Resonance of Patterned Magnetic Nanostructures; Under progress

b) Post-Docs

1. Arpan Bhattacharya; Spin-Orbit Effects in Magnonics

c) External Project Students / Summer Training

1. Shreya Mehta; Investigation of Magnetization Reversal Mechanism of Ferromagnetic Nanostructures using Micromagnetic Simulation; Pt. Ravishankar Shukla University, Raipur

Teaching

1. Autumn semester; PHY301: Atomic and Molecular Physics; Integrated PhD; 12 students; with 1 (Prof. Rajib Kumar Mitra) co-teachers

2. Autumn semester; CB 527: Molecular Physics and Spectroscopy; PhD; 3 students; with 1 (Prof. Rajib Kumar Mitra) co-teacher

3. Spring semester; PHY401: Project Research III; Integrated PhD; 2 students

Publications

a) In journals

1. Anulekha De, Koustuv Dutta, Sucheta Mondal, Saswati Barman, Yoshichika Otani, and **Anjan Barman**, *Magnonic crystals with complex geometry*, Physical Review B, 103, 064402, 2021

2. Sourav Sahoo, Surya Narayan Panda, Saswati Barman, Yoshichika Otani and **Anjan Barman**, *Nanochannels for spin-wave manipulation in $Ni_{80}Fe_{20}$ nanodot arrays*, Journal of Magnetism and Magnetic Materials, 522, 167550, 2021

3. **Anjan Barman**, Sucheta Mondal, Sourav Sahoo, and Anulekha De, *Magnetization dynamics of nanoscale magnetic materials: A perspective*, Journal of Applied Physics 128, 170901, 2020

4. M.R.Karim, D.Panda, A.Adhikari, P.Sharangi, P.Mandal, S.Ghosh, S.Bedanta, **A.Barman** and I.Sarkar, *Electrodeposited Heusler alloy films with enhanced magneto-optical property*, Materials Today Communications, 25, 101678, 2020

5. Samiran Choudhury, Avinash Kumar Chaurasiya, Amrit Kumar Mondal, Bivas Rana, Katsuya Miura, Hiromasa Takahashi, YoshiChika Otani and **Anjan Barman**, *Voltage controlled on-demand magnonic nanochannels*, Science Advances, 6, eaba5457, 2020

6. Justine Lynn Drobitch, Anulekha De, K. Dutta, Pratap Kumar Pal, Arundhati Adhikari, **Anjan Barman** and Supriyo Bandyopadhyay, *Extreme Subwavelength Magnetoelastic Electromagnetic Antenna Implemented with Multiferroic Nanomagnets*, Advanced Materials Technologies, 5, 2000316, 2020

7. Amrit Kumar Mondal, Chandrima Banerjee, Arundhati Adhikari, Avinash Kumar Chaurasiya, Samiran Choudhury, Jaivardhan Sinha, Saswati Barman, and **Anjan Barman**, *Spin-texture driven reconfigurable magnonics in chains of connected $Ni_{80}Fe_{20}$ submicron dots*, Physical Review B, 101, 224426, 2020

8. Akash Kumar, Avinash Kumar Chaurasiya, Niru Chowdhury, Amrit Kumar Mondal, Rajni Bansal, Arun Barvat, Suraj P. Khanna, Prabir Pal, Sujeet Chaudhary, **Anjan Barman** and P. K. Muduli, *Direct measurement of interfacial Dzyaloshinskii–Moriya interaction at the $MoS_2/Ni_{80}Fe_{20}$ interface*, Applied Physics Letters, 116, 232405, 2020

9. Santanu Pan, Takeshi Seki, Koki Takanashi, and **Anjan Barman**, *Ultrafast demagnetization mechanism in half-metallic Heusler alloy thin films controlled by the Fermi level*, Physical Review B, 101, 224412, 2020

10. Sujit Deshmukh, Debosmita Banerjee, Gourav Bhattacharya, Sam J. Fishlock, **Anjan Barman**, James McLaughlin, and Susanta Sinha Roy, *Red Mud-Reduced Graphene Oxide Nanocomposites for the Electrochemical Sensing of Arsenic*, ACS Applied Nano Materials, 3, 4084-4090, 2020

Talks / Seminars Delivered in reputed conference / institutions

1. Spin-Orbit Effects in Spintronics, W2S Webinar on Spintronics; Jun 11, 2020; NISER Bhubneswar (Online Mode); 60 min

2. Spin-Orbit Effects in Spin Dynamics, The 2020 Around-the-Clock Around-the-Globe Magnetics Conference; Aug 27, 2021; IEEE Magnetics Society (Online Mode); 45 min

3. Interface Driven Ultrafast Spin Dynamics in Ferromagnet/Nonmagnet and Ferromagnet/2D Material Heterostructures, 3rd International Conference on Quantum Condensed Matter (QMAT 2020); Sep 7, 2020; S. N. Bose National Centre for Basic Sciences (Online Mode); 30 min

4. Emergent Magnonic Phenomena in Magnetic Thin Films and Nanostructures, International Conference on Emerging Electronics (ICEE 2020); Nov 26, 2020; IIT Delhi (Online Mode); 30 min

5. Squeezing the Time and Length Scale for New Generation Spintronics, Emerging Trends in

Research Methodology in Condensed Matter, Materials Science and Nanoscience (ETRMCMMSN) 2020; Dec 1, 2021; Neotia University, KOlkata (Online Mode); 45 min

6. Ultrafast spin dynamics in graphene/ferromagnet thin film heterostructures, The 4th International Symposium for CRC Spintronics; Feb 24, 2021; Tohoku University, Japan (Online Mode); 30 min
7. Application of Spin-Orbit Effects in Spintronic and Magnonic Devices, Current Trends in Materials Science and Engineering (CTMSE-2021); Mar 13, 2021; IEM Kolkata (Online Mode); 45 min

Administrative duties

1. Associate Dean (Faculty)
2. Member of the Technical Cell Advisory Committee
3. Member of the Faculty Search Committee
4. Convenor of APMP

Membership of Learned Societies

1. Member of American Physical Society
2. Member of IEEE
3. Life Member of MRSI

Extramural Projects (DST, CSIR, DAE, UNDP, etc.)

1. Center for Nanomagnetics for Energy Efficient Computing, Communications and Data Storage; Indo-US Virtual Networked Centre; 2019 - 2021; PI

Scientific collaborations with other national / international institutions (based on joint publications)

1. Prof. Yoshichika Otani, RIKEN-CEMS, Wako and Univ. of Tokyo, Japan; Sl. No. 1, 2, 5; International
2. Prof. Supriyo Bandyopadhyay, Virginia Commonwealth University, USA; Sl. No. 6; International
3. Prof. K. Takanshi and Dr. T. Seki, Tohoku University, Japan; Sl. No. 9; International
4. Prof. P. K. Muduli, IIT Delhi; Sl. No. 8; National
5. Dr. Indranil Sarkar, INST, Mohali; Sl. No. 4; National
6. Prof. S. S. Roy, Shiv Nadar University; Sl. No. 10; National

Outreach program organized / participated

1. A New Spin on Next generation Computing, A. Barman, Vigyan-Jyoti Programme of DST, Oct. 6, 2021 (lecture and virtual lab visit).

Areas of Research

Experimental Condensed Matter Physics, Nanomagnetism, Spintronics, Magnonics, Ultrafast Dynamics, Spectroscopy

A. Development of on-demand and reconfigurable magnonic nanochannels: Development of energy-efficient magnonic nanochannels (MNCs) can revolutionize on-chip data communication and processing. We have developed a dynamic MNC array by periodically tailoring perpendicular magnetic anisotropy using electric field. We used Brillouin light scattering spectroscopy to probe the spin-wave (SW) dispersion of MNCs formed by applying a static electric field at the CoFeB/MgO interface through a one-dimensional stripe-like array of indium tin oxide electrodes placed on top of Ta/CoFeB/MgO/Al_2O_3 heterostructures. Magnonic bands, consisting of two SW frequency modes, appear with a bandgap under the application of moderate gate voltage, which can be switched off by withdrawing the voltage. Simulated SW mode profiles show propagating SWs through nanochannels with different magnetic properties. The anticrossing between these two modes gives rise to the observed magnonic bandgap.

B. Development of extreme subwavelength magnetoelastic electromagnetic antenna using two-phase multiferroic nanomagnets: Emission/radiation efficiency of antenna is limited by emission area and wavelength making it challenging to miniaturize antennas to extreme subwavelength dimensions without severely compromising their efficiencies. We have

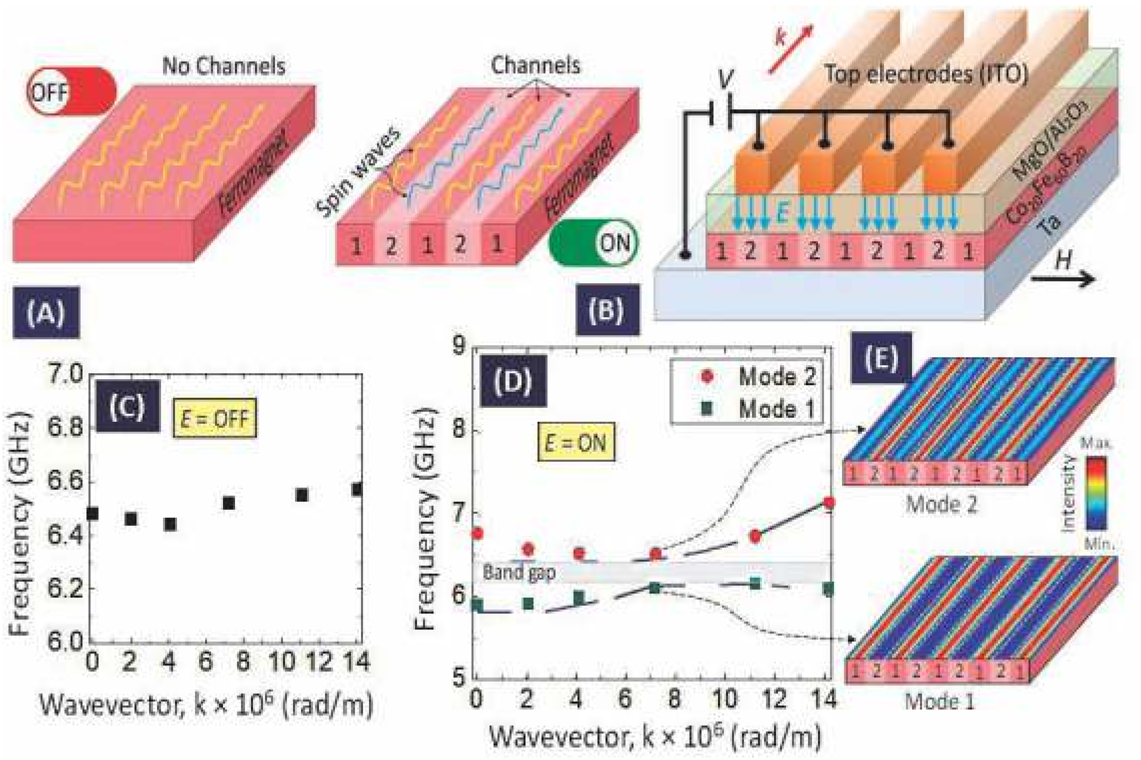

Fig. 1: A. Schematic illustration shows the concept of spin wave nanochannels. B. Schematic illustration shows the device structure and formation of nanochannels. Spin-wave frequencies versus wavevector when electric field, E is OFF (C) and ON (D). E. Heatmap plots show the spatial distribution of spin-wave intensity for spin-wave mode 2 and mode 1 at wavevector $k = 7.1 \times 10^6$ rad/m.

overcome this challenge by actuating an electromagnetic (EM) antenna made of magnetostrictive nanomagnets deposited on a piezoelectric substrate by surface acoustic wave (SAW) whose wavelength is about five orders of magnitude smaller than the EM wavelength at the same frequency. These extreme subwavelength antennas allow drastic miniaturization of communication systems.

C. Fermi level controlled ultrafast spin dynamics in Heusler alloy thin films: We have demonstrated electronic band-structure controlled ultrafast demagnetization mechanism in $Co_2Fe_xMn_{1-x}Si$ Heusler alloy thin films by systematic variation of composition. The spin-flip scattering rate controlled by spin-density of states at the Fermi level is found to be responsible for a nonmonotonic variation of demagnetization time with composition with a maximum at $x = 0.4$. An inverse relation of demagnetization time with Gilbert damping indicates the dominance of interband scattering mechanism. This establishes a correlation between ultrafast demagnetization and magnetic damping based on Fermi-level position in this Heusler alloy system.

D. Spin-texture driven reconfigurable magnonics in ferromagnetic nanodot array: We have demonstrated reconfigurable magnonic band structure and band gap by a bias-field controlled spin texture in chains of connected Ni80Fe20 nanodots. For an identical field value, we could achieve both "*S*" and shifted-core vortex states based on magnetic history leading to a drastic change in magnonic band structure. A first-order phase transition from magnetic saturated to vortex state drives this change, as opposed to a continuous change from the saturation to *S* state.

E. Observation of interfacial Dzyaloshinskii–Moriya interaction at the $MoS_2/Ni_{80}Fe_{20}$ interface: We have directly measured interfacial Dzyaloshinskii–Moriya interaction (iDMI) at the interface of MoS_2 and $Ni_{80}Fe_{20}$ (Py), using Brillouin light scattering spectroscopy. A clear asymmetry in spin-wave dispersion is observed in

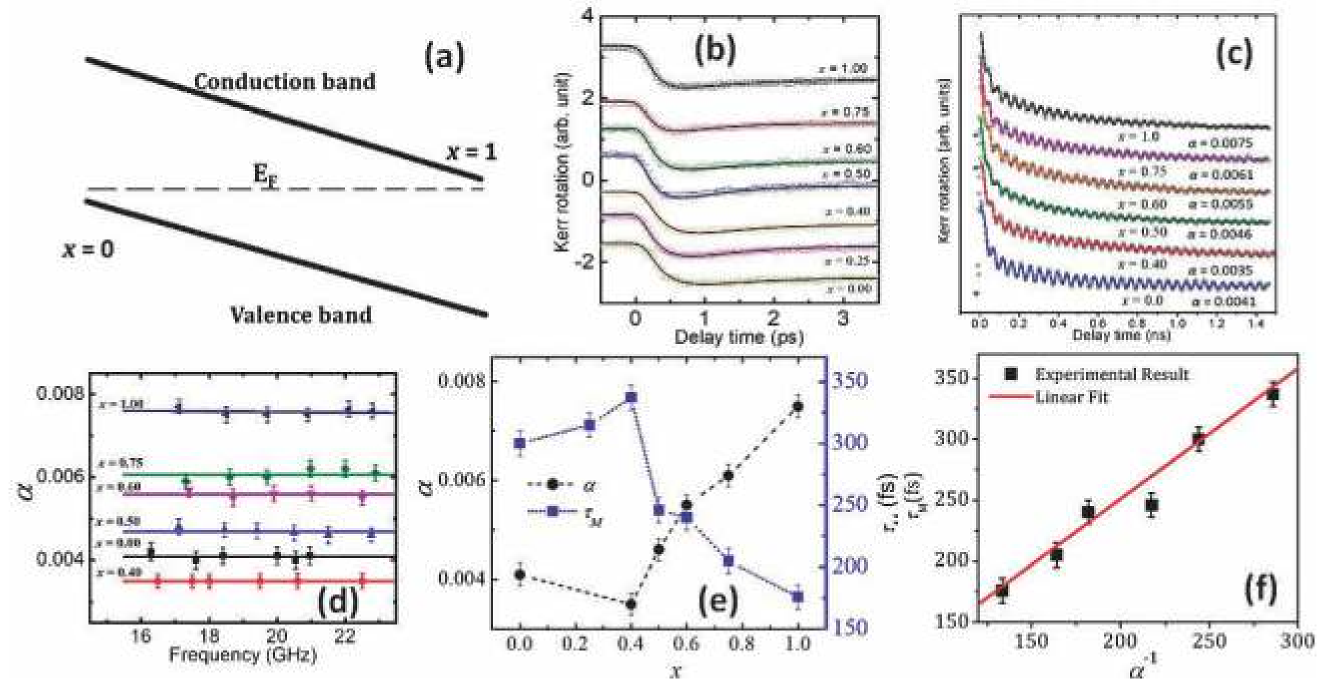

Fig. 2: A. Schematic of composition-dependent band structure of CFMS Heusler alloy. Time-resolved B. ultrafast demagnetization and C. precessional dynamics. D. Damping as a function of frequency. E. Variation of damping and demagnetization time with composition. F. Correlation between demagnetization time and damping.

MoS_2/Py/Ta due to the iDMI. Linear scaling of the iDMI constant with the inverse of Py thickness indicates the interfacial origin of the iDMI. We further observe an enhancement of iDMI constant in 3-4 layer MoS_2/Py system as compared to that in two layer MoS_2/Py, caused by a higher density of MoO_3 defect species.

Plan of Future Work Including Project

1. We plan to study interfacial spin transparency and spin-mixing conductance in W (t)/$Co_{20}Fe_{60}B_{20}$ (d)/SiO_2 (2 nm) thin-film heterostructures and study its dependence on the crystalline phase of W as a function of its thickness. Effects such as spin memory loss and two-magnon scattering will be investigated.

2. We will study coherent spin waves within a three-dimensional artificial spin ice (ASI) structure made of connected nanowires in a diamond bond lattice using Brillouin light scattering. The 3DASI was fabricated by using a combination of two-photon lithography and thermal evaporation.

3. We will study spin-wave response of two different two-dimensional kagome ASI nanostructures via Brillouin light scattering, a continuously connected system and a disconnected system with vertex gaps. This motivated by the comparison of how the dipolar coupling and dipole-exchange coupling mediated magnetic microstates affect the spin-wave dynamics?

4. We will study the effects of surface acoustic waves on the spin-wave dynamics in a densely packed array of two-phase multiferroic nanomagnets made of Co nanodots patterned on $LiNbO_3$ substrate. Such strongly magnetostatically coupled nanomagnets will show natural resonant spin-wave modes in absence of a bias magnetic field. We will study the possibility of resonant amplification of intrinsic magnetic modes and generation of new extrinsic (driven) modes in this system. The amplification factor and nature of resonant and non-resonant modes will be extensively studied.

5. We will study 'magnon-magnon coupling' in an array of cross-shaped $Ni_{80}Fe_{20}$ nanorings, each of which will act as a resonant nano-cavity for the magon eigenmodes. The tailored inter- and intra-element dipolar couplings may lead to the strongly coupled modes with high cooperativity and opening large anticrossing gaps. We will study the coherent propagation of the hybrid modes as opposed to the uncoupled eigenmodes.

Any other Relevant Information including social impact of research

1. Initiated new and emerging research fields such as magnonics, spintronics and spin-orbitronics for enabling India to compete at the international level.
2. Developed novel research facilities such as Time-resolved Magneto-optical Kerr Effect Microscopy, Micro-focused Brillouin Light Scattering and spin-torque FMR for the first time in India for the experimental studies of magnonics and spintronics.
3. Played advisory role to several young scientists in India for developing the above research fields and facilities.
4. Generated knowledge base for applications in magnetic data storage, memory, logic and communication devices.
5. Trained Masters and PhD students and Postdoctoral scientists for the development of future science and technology in India.