

# **National Conference on AI & ML Driven Recent Advances in Condensed Matter and High Energy Physics**

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Ewing Christian College

## **Book of Abstracts**



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1

## Non-extensivity impacts on Hadronic Drag and Diffusion coefficients

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**Co-author:** Swatantra Kumar Tiwari

In this work, we analyze the drag and diffusion coefficients of hadrons propagating in a thermal hadronic medium using the Fokker–Planck equation formulated within the Tsallis non-extensive statistical framework. The Tsallis non-extensive parameter  $q$  quantifies the deviation from equilibrium ( $q > 1$ ) and provides for a more realistic description of the medium, not perfectly thermalized. The hadronic bath, consisting of various mesonic and baryonic species, is controlled by different mass cutoffs which constitutes the spectral composition of the medium. Our analysis shows that both the drag coefficient  $F$  and the momentum diffusion coefficients  $\Gamma$  increases exponentially with temperature and a systematic increase with increasing  $q$  and mass cutoffs. The spatial diffusion coefficient  $D_x$  exhibits a decreasing trend with temperature  $T$ , non extensive parameter  $q$  and mass cutoffs which highlights the significant influence of non-equilibrium effects and hadronic composition of hadronic medium on the transport behaviour of propagating hadrons.

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## Non-extensivity impacts on Hadronic Drag and Diffusion coefficients

**Author:** Aditya Kumar Singh<sup>None</sup>

**Co-author:** Swatantra Kumar Tiwari

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## Potential Application of Emulsion Technology in Healthcare

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There is a lot of promise for developing radiopharmaceutical carrier systems using emulsion technology. Radiopharmaceuticals, which aid in the diagnosis and treatment of several illnesses, including

cancer, are crucial to nuclear medicine. A variety of widely accepted safe materials may be used to make particles with various compositions, sizes, forms, and surface properties, enabling their utility to be customized for particular purposes. The structure of emulsion formulation consists of an external phase and an internal phase. Oil in water or water in oil (i.e., O/W or W/O) emulsion and water in oil in water or oil in water in oil (i.e., W/O/W or O/W/O) triple emulsion are two forms of emulsions that may be differentiated based on the phases' structure and characteristics. Emulsion preparation methods are also suitable for use in medical applications since they are frequently simple, inexpensive, dependable, and scalable. The article highlights various potential applications of emulsion technology in the healthcare sector.

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## Charm quark energy loss and D meson nuclear modification factor in PbPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV

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First we calculate the transverse momentum ( $p_T$ ) spectra of D meson in proton-proton (pp) collision at  $\sqrt{s} = 5.02$  TeV and compare with the CMS measurements of D meson. The calculation describes the measured data very well. We use a hydrodynamic picture for Quark-Gluon Plasma (QGP) evolution during which  $p_T$  spectra of charm quark is modified due to collision and radiative energy loss. We use Peigne and Peshier formalism to calculate the collisional energy loss and Reaction operator formalism (DGLV) and Generalized dead cone approach to calculate the radiative energy loss. We performed the calculation of D meson nuclear modification factor  $R_{AA}$  in PbPb collision at  $\sqrt{s_{NN}} = 5.02$  TeV for the kinematic region covered by CMS experiments. The radiative energy loss from generalized dead cone approach alone is sufficient to produce D meson  $R_{AA}$ . The radiative energy loss from DGLV formalism plus collisional energy loss gives good description of D meson  $R_{AA}$ .

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## Mirrors That Hear the Universe: The Coating Technology Behind LIGO's Gravitational Wave Detection

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In Einstein's general theory of relativity, gravitational waves were initially predicted in 1916. According to him these cataclysmic events produce brief perturbations in spacetime curvature that

propagate outward as GW ripples. These waves convey energy in the form of gravitational radiation and move at the speed of light. The Laser Interferometer Gravitational-Wave Observatory (LIGO) uses kilometer-scale Michelson interferometers to measure length changes smaller than one-thousandth of a proton's diameter, which is necessary to detect these incredibly faint signals. The interferometer's mirrors, whose performance is largely dictated by their optical coating technology, are at the centre of this extraordinary sensitivity. This study focused how multi-layer dielectric mirror coatings with ultra-high reflectivity allow LIGO to attain the extraordinary precision needed for gravitational wave detection. We go into the materials used, the strict specifications on optical loss, surface roughness, and mechanical dissipation, and the physical concepts of thin-film interference used to develop these coatings. Nowadays, gravitational wave detectors function as modified Michelson interferometers, with thermal noise from the highly reflective mirror coatings placing a crucial limit on the sensitivity of both present and future devices.

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## Robust Low- $z$ Hubble Constant Determination Using Machine Learning Assisted Outlier Detection of Type Ia Supernovae from the NED-D Dataset

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### Abstract

**Context:** Accurate determination of the Hubble constant ( $H_0$ ) using low-redshift Type Ia supernovae (SNIa) is critical for precision cosmology. Outliers in distance measurements act like noise in high-precision experimental data, potentially biasing results, similar to errors in beam-based imaging systems.

**Purpose:** We develop a reproducible pipeline for low- $z$   $H_0$  estimation, explicitly motivated by applications requiring high-precision, noise-resilient measurements in imaging-intensive experimental setups. The goal is to minimize the impact of anomalous SNIa while ensuring reliable results.

**Methods:** The NED-D SNIa dataset is analyzed using Isolation Forests to detect and remove outliers with inconsistent distances or velocities. Weighted  $H_0$  is calculated from the cleaned sample, and bootstrap resampling is employed to quantify uncertainties. An interactive exploration of outliers is provided, highlighting SNIa that strongly influence  $H_0$ .

**Findings:** The cleaned sample yields  $H_0 \approx 66\text{--}68$  km/s/Mpc with uncertainties around 1 km/s/Mpc. Outlier removal significantly reduces bias and variance. The ranked outlier table identifies influential supernovae, analogous to pinpointing critical deviations in experimental imaging systems.

**Significance:** Machine learning-assisted outlier detection combined with reproducible uncertainty quantification provides a robust framework for high-precision cosmological measurements. This approach mirrors strategies in beam diagnostics and imaging experiments, where reliable anomaly detection and uncertainty control are crucial for accurate interpretation.

**Keywords:** Hubble constant; Low-redshift supernovae; Isolation Forest; Bootstrap uncertainty; Weighted  $H_0$ ; Robust measurement; Imaging diagnostics.

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## Discovery Reach of Neutrinoless Double-Beta Decay

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Neutrinoless double-beta decay ( $0\nu\beta\beta$ ) is a lepton-number-violating nuclear process that, if observed, would provide direct evidence for Majorana neutrinos and insight into the absolute neutrino mass scale. The next generation of  $0\nu\beta\beta$  experiments, employing a broad range of candidate isotopes, are designed to fully probe the inverted mass hierarchy and to extend sensitivity into the normal hierarchy. Recent cosmological indications favoring the normal hierarchy further motivate this effort, although probing this region remains challenging under the current theoretical uncertainties associated with nuclear matrix elements. Recognizing the critical impact of theoretical inputs on the design and interpretation of experimental searches, this work systematically incorporates uncertainties in nuclear matrix elements, the axial-vector coupling, and phase-space factors, particularly emphasizing nuclear matrix elements, spanning recent ab-initio and phenomenological nuclear-structure calculations, to evaluate the projected sensitivity of forthcoming  $0\nu\beta\beta$  experiments.

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## Galaxy 2D to 3D Depth Visualization –Cosmic Eye (NGC 2566) using MiDaS and Accuracy Evaluation using SSIM

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### Abstract

**Context:** Accurate 3D reconstruction from 2D images is vital for both astronomical studies and imaging-intensive experimental systems, where structural identification under limited resolution and noise is crucial.

**Purpose:** This work evaluates the MiDaS DPT-Large model on synthetic galaxy images with ground-truth depth maps, motivated by applications requiring precise structural detection for monitoring and alignment in experimental setups.

**Methods:** Synthetic datasets simulating galaxies with bulges and rings were generated. Depth maps predicted by MiDaS were compared to ground truth using SSIM, and Canny edge detection was applied to assess structural correspondence.

**Findings:** Direct SSIM averaged 0.4508, while edge-based SSIM reached 0.9253, showing strong preservation of morphological boundaries. Batch testing over ten images yielded SSIM from 0.3370 to 0.5337. 3D visualizations highlighted accurate recovery of global structures, though fine ring details remain challenging.

**Significance:** Monocular depth estimation demonstrates potential for structural analysis and real-time monitoring in imaging-intensive experimental systems, including beam diagnostic and alignment applications.

**Keywords:** Galaxy 3D reconstruction; monocular depth estimation; MiDaS; SSIM; synthetic galaxy images; imaging diagnostics

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## Advantage of Nuclear Emulsion Detector in Rare Event Searches

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A type of photographic emulsion known as “nuclear emulsion” reveals the passage of charged particles during chemical development and leaves behind visual traces of silver grains. In addition to its remarkable spatial resolution, capacity to serve as both a tracking and target device, and excellent signal-to-noise ratio for particular kinds of reactions, nuclear emulsion detectors (NED) provide distinct benefits in rare event searches. The NED applications for directional dark matter searches, exotic particle detection, and high-precision particle trajectory imaging to probe nuclear interactions will be the main focus of this work.

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## Use of Nuclear Emulsion Detector in Different Field

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In this paper we have discuss about the nuclear emulsion detector and its uses in current research. And know about what is the use of nuclear emulsion detector in different field like Neutrino search, Dark matter search and Medical field and also discuss about that how nuclear emulsion detector in work in medical field, Dark matter and Neutrino search and why this detector use in these field we have discuss about in this paper.

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## Study the Target Effect in Pseudorapidity Distribution of Shower Particles at Relativistic Energy

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In relativistic heavy-ion collisions, pseudorapidity is an important kinematic characteristic because it directly reveals the angular emission pattern, longitudinal dynamics, and multiparticle creation mechanisms of secondary particles. Because pseudorapidity simply depends on the emission angle and roughly resembles rapidity at relativistic energies, it is important in nuclear emulsion studies when momentum information is not immediately available. Thus, pseudorapidity distributions' shape, width, and target dependency function as sensitive probes of the space-time evolution of the participant region created during the collision. The pseudorapidity distributions of shower particles released in krypton–emulsion interactions with an incidence energy of 1 A GeV are thoroughly examined in this publication. In order to investigate target-mass effects, the analysis compares interactions with heavy (AgBr) and light (CNO) target nuclei incorporated in the emulsion. The observation shows that Gaussian functions properly clarify the pseudorapidity distributions, suggesting that particle emission is collective in nature. A pronounced enhancement

in particle density is observed for AgBr targets relative to CNO targets, highlighting the significant influence of target size on particle production.

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## Investigating the variability of self-affine multiplicity for the events generated at relativistic energy for 84Kr-AgBr reactions

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The two-dimensional factorial moment approach and the idea of the Hurst exponent (H) are used to study self-affine multiplicity fluctuation. It is suggested that the anisotropy of phase space causes the regional differences in multiplicity at relativistic energy multiparticle creation to be self-affine rather than self-similar. The best power law behaviors are shown at H=0.7 for compound particles released in 84Kr-AgBr reactions at 1 A GeV. Additionally, covered are the multifractality and non-thermal phase change that take place in the production of the compound particles in 84Kr-AgBr interaction. There is no indication of a non-thermal phase change in the synthesis of compound particles.

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## Self-Affine Surface Evolution and Monofractal Analysis of Ag Ion-Irradiated ZnO Thin Films

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Zinc oxide (ZnO) thin films with a thickness of 120 nm were deposited on Si substrates maintained at 300 °C using the electron beam evaporation technique. The deposited films were subsequently irradiated with 100 MeV Ag ions at various fluences of  $1 \times 10^{10}$ ,  $5 \times 10^{10}$ ,  $1 \times 10^{11}$ ,  $3 \times 10^{11}$ ,  $7 \times 10^{11}$ ,  $1 \times 10^{12}$ ,  $1 \times 10^{13}$ , and  $3 \times 10^{13}$  ions/cm<sup>2</sup>. High-energy heavy ion irradiation resulted in the formation of self-affine nanostructures on the ZnO thin film surfaces. Atomic force microscopy (AFM) was employed to obtain topographical images of both pristine and ion-irradiated films. Classical surface roughness parameters, including arithmetic mean roughness (Sa), root mean square roughness (Sq), skewness (Ssk), kurtosis (Sku), peak height (Sp), and valley depth (Sv), were evaluated for each surface. Shannon entropy was used to quantify the topographical uniformity of the rough surfaces. Minkowski functionals were applied for the quantitative analysis of geometrical and topological surface features. Furthermore, surface complexity and growth behavior in both lateral and vertical directions were analyzed using monofractal parameters. Monofractal surfaces are characterized by homogeneous scaling properties, exhibiting uniform scaling behavior described by a single singularity exponent.

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## Identifying background sources and their impacts at sub-keV energy region for rare event searches with Ge detectors

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The TEXONO Collaboration has established a detection system with an ultra-low energy high purity germanium detector at Kuo-Sheng Nuclear Power Plant to monitor neutrino–nucleus coherent scattering and to seek for dark matter. Understanding background origins and their impact to the energy spectrum is crucial in this experiment because of the weak nature and

modest recoil energy of these uncommon events. During detector maintenance in non-operational conditions above ground, high-energy neutron-induced interactions inside the

Germanium crystal yield tritium (<sup>3</sup>H). The varied Ge isotopes and neutron kinetic energy produced by TENDL2015 determine the generation cross-section of <sup>3</sup>H and <sup>68</sup>Ge, respectively. Fast cosmic-ray neutrons can form isotopes in Ge that can cause background in dark matter studies. When solar activity is at its lowest, the cosmic ray-induced neutron flux is at its highest, and vice-versa. The observed differential flux of neutrons caused by cosmic rays as a function of neutron energy at the KSNL experimental site and their effects on sub-keV energy domains will be the main focus of this study.

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## Listening to the Universe: Gravitational Waves as a New Probe of Fundamental Physics

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Since the first successful detection in 2015, the area of gravitational wave research has advanced quickly, bringing in a new age in astronomy. We focus over the benefits and drawbacks of existing ground-based observatories like LIGO and, Virgo as well as the critical role of future third-generation detectors like the Einstein Telescope and space-based missions like LISA. Improvements in cryogenic technology, increased frequency coverage, and integration with multi-messenger astronomy are highlighted as important areas of study. GW astronomy has become a key component of contemporary observational astrophysics thanks to ground-based interferometers like Virgo, KAGRA, and LIGO, which made groundbreaking discoveries. The low-frequency sensitivity and horizon reach of the current generation of detectors are nevertheless constrained by a number of fundamental and technical noise sources, such as quantum shot noise, thermal Brownian motion in optical coatings, seismic disturbances, and suspension-related thermal fluctuations. Next-generation observatories like LIGO-India, the Einstein Telescope (ET), and the Cosmic Explorer (CE) are being built with revolutionary technological advancements to overcome these obstacles. This study explains the state of gravitational wave detection today and considers potential future paths that could deepen our comprehension of the cosmos.

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## Distinguishing Surface from Bulk Events in Point-Contact Germanium Detectors for Neutrino and Dark Matter Detection

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The TEXONO collaboration conducted neutrino-nucleus scattering studies and light dark matter investigations using germanium detectors with sub-keV sensitivity. By raising the detector mass from 500g to 1500g, the TEXONO collaboration has gradually progressed the usage of PCGe detectors over time, greatly improving sensitivity to low energy events pertinent to neutrino and dark matter studies. In addition to this scaling in detector mass, significant efforts have been made to address the ongoing difficulty of differentiating surface-originated background signals from genuine bulk interactions, especially in the low-energy area where the rise-time starts to intersect. In order to identify signals at levels equivalent to electronic noise, subsequent research concentrated on improving energy reconstruction and noise suppression. The method's resilience is confirmed by actual data from the enhanced 1500g PCGe detector, shows that S/B events can be distinguished up to the electronic noise edge for sub-keV rare event searches. In this work, timing pulse data from various PCGe detector masses obtained at the TEXONO reactor experiment will be used to demonstrate how S/B discriminating techniques are optimized.

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## Identifying axions in magnetized matter of neutron star

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Quantum chromodynamics (QCD) axions might solve the mystery of an exact candidate for dark matter (DM). Axions are weakly interacting particles, motivated by the solutions to the strong CP problem physics. The cooling process of neutron stars (NS) occurs through the emission of particles, including neutrinos and axions.

By employing the SLY equation of state (EoS), we solve the modified Tolman-Oppenheimer-Volkoff (TOV) set of equations. We take into account the Bremsstrahlung process that occurs in both the core and crust of the NS. Additionally, we analyze the influence of strong magnetic fields on the luminosity versus the ages of NSs for different masses of axions.

We utilize the maximum permissible limit for the central magnetic field and a radially distance-dependent expression for the magnetic field while generating profiles using the TOV equations. The

luminosity of axions produced through the Bremsstrahlung process is significantly higher in the presence of a magnetic field compared to without magnetic field, particularly during the early stages of the NS, within the possible range of axion masses. When a magnetic field is included, we observe a

notable difference in the luminosity of axions for all characteristic ages of NSs. Our analysis indicates that the luminosity of particles, such as axions and neutrinos, in the cooling of NSs is largely affected by the presence of an intense magnetic field. With the inclusion of magnetic fields in the EoS and various processes related to the cooling of NSs, we can achieve a better understanding of the underlying physics of the universe. The current results address fundamental questions regarding the formation of stars and galaxies by observing their gravitational effects and electromagnetic radiation.

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## Study of Quark-Gluon Plasma in Relativistic Heavy-Ion Collisions

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The study of quark-gluon plasma (QGP) is one of the most important research areas in modern high-energy physics. According to Quantum Chromodynamics (QCD), strongly interacting matter undergoes a phase transition from hadronic matter to a deconfined state of quarks and gluons at extremely high temperatures and energy densities. Such conditions can be recreated in laboratories through relativistic heavy-ion collisions at facilities such as the Relativistic Heavy Ion Collider (RHIC) and the Large Hadron Collider (LHC). This research paper presents a detailed discussion of the theoretical foundations of QGP, experimental methods used in heavy-ion collisions, and key signatures such as collective flow, jet quenching, and strangeness enhancement. The results provide compelling evidence for the formation of a strongly interacting, nearly perfect fluid known as the quark gluon plasma.

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## Multi-Flux-Tube representation of dual QCD Vacuum

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To explore the typical non-perturbative structure of QCD vacuum, a dual version of color gauge theory has been analysed. The QCD vacuum, in physically accessible near infrared sector has been shown to endowed with a multi-flux-tube system. Using the first principle, the flux tube energy in the asymptomatic limit has been computed at various couplings. Consequently, the interaction among microscopic color flux-tubes has been shown to reveal their possible role in the low energy phenomenon of QCD vacuum.

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## Thermal Noise Reduction Using Multilayer Insulation in LIGO Gravitational Wave Detectors

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The Laser Interferometer Gravitational-Wave Observatory (LIGO) detects gravitational waves by measuring minute changes in the lengths of its kilometer-scale interferometer arms with unprecedented precision. Such extreme sensitivity requires stringent suppression of thermal and environmental noise sources that can mask or mimic gravitational-wave signals. The multilayer insulation (MLI) technique plays an important role in thermal management within vacuum and cryogenic subsystems associated with advanced gravitational-wave detectors. MLI, composed of multiple alternating layers of low-emissivity reflective films and insulating spacers, significantly reduces radiative heat transfer in high-vacuum environments. By minimizing temperature fluctuations and thermal gradients around critical components such as vacuum chambers, suspension systems, and optical assemblies, MLI helps maintain dimensional stability and reduces thermally induced mechanical noise. In proposed and next-generation cryogenic upgrades, effective radiative shielding using MLI becomes even more crucial for preserving mirror quality and limiting thermal drift. Thus, the implementation of multilayer insulation contributes indirectly but significantly to enhancing detector sensitivity, operational stability, and the long-term performance of LIGO and future gravitational-wave observatories.

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## Machine Learning Assisted Detection of Topological Phases in the Quasi-Periodic Extended Su-Schrieffer-Heeger (SSH) Model

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Topological Anderson Insulator (TAI) phase is often hard to characterize as it is driven by disorder. While Su-Schrieffer-Heeger (SSH) system is well understood but its long-ranged hopping and quasi-periodically disordered extensions offer a topologically richer landscape. Calculation of conventional topological invariants like real space winding numbers in such a system become both a numerically unstable and computationally expensive exercise as they lack translational symmetry. In this work we have proposed a machine learning framework for the identification of topological phases by training an Artificial Neural Network (ANN) that spots these phases by focusing on coalescence of central eigen modes into edge localized zero energy modes under open boundary conditions (OBCs). We have performed a comparative analysis which showcases superiority of ANN based approach over traditional winding number calculations in accurate classification of phases even in the regions where invariants fluctuate traditionally. Our results demonstrate that spectral feature learning is a robust method for identifying disordered topological phases, contributing to the growing intersection of machine learning and condensed matter physics.

**Keywords:** Topological Anderson Insulator, Quasi-Periodic Systems, Artificial Neural Networks, SSH Model, Phase Transitions.

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## Thermal Noise Reduction Using Multilayer Insulation in LIGO Gravitational Wave Detectors

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## Exploring Machine Learning to study Charged Particle Multiplicity and Transverse Momentum distributions with pp collisions at LHC

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Charged particle multiplicity and transverse momentum distributions in proton-proton (pp) collisions at LHC are key observables for characterizing particle production as a function of collision energy and pseudorapidity. We aim to understand the correlation between particle production by modelling the relationship between particle multiplicity and its probability distribution. Charged-particle multiplicity and transverse-momentum distributions within different pseudorapidity intervals in pp collisions were simulated using the PYTHIA8 event generator with several centres of mass energies for model training. Machine learning techniques, such as Deep Neural Network (DNN) and Convolutional Neural Network (CNN) are explored to fit multiplicity distributions in high energy pp collisions and compared in their ability to predict charged particle multiplicity and transverse momentum spectra across different center of mass energies and eta intervals. The probability distributions are used to compare Model's performance. This study demonstrates the potential of neural networks for describing multidimensional particle observables in pp collisions at LHC energies.

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## Probing the Validity of Effective Field Theory Approaches in Higgs + Jet Production at $\sqrt{s} = 13$ TeV

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The production of a Higgs boson in association with a jet is one of the most important processes studied at the LHC. It serves as a sensitive probe of high-energy dynamics and provides a powerful testing ground for the Standard Model, while also offering sensitivity to possible new physics effects. In phenomenological analyses, loop-induced contributions are often approximated using effective frameworks such as the Higgs Effective Field Theory (HEFT) or the Standard Model Effective Field Theory (SMEFT), which greatly simplify the calculations. However, the reliability of these approximations must be carefully evaluated, particularly in kinematic regimes characterized by large momentum transfer.

In this work, we perform a simulation-level analysis of Higgs plus jet production at  $\sqrt{s} = 13$  TeV. We compare predictions obtained from the full loop-induced Standard Model with those derived within the HEFT and SMEFT frameworks. Taking the Higgs transverse momentum as a key observable, we study normalized distributions, ratio spectra, and integrated deviations above various transverse-momentum thresholds to quantitatively assess the validity of the effective descriptions.

Our results show that effective approaches successfully reproduce the Standard Model behavior in the low transverse-momentum region. However, sizable deviations emerge at high  $p_T$ ,

signaling the breakdown of the effective approximation. These findings highlight the importance of carefully accounting for kinematic effects when applying EFT-based methods to precision Higgs studies and provide a quantitative estimate of their range of validity.

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## Probing the Validity of Effective Field Theory Approaches in Higgs + Jet Production at $\sqrt{s} = 13$ TeV

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In this work, we perform a generation-level analysis of Higgs plus jet production at  $\sqrt{s} = 13$  TeV, using MadGraph5\_aMC@NLO framework. We compare predictions obtained from the full loop-induced Standard Model with those derived within the HEFT and SMEFT frameworks. Taking the Higgs transverse momentum as a key observable, we study normalized distributions and ratio spectra above various transverse-momentum thresholds to quantitatively assess the validity of the effective descriptions.

Our results show that effective approaches successfully reproduce the Standard Model behavior in the low transverse-momentum region. However, sizable deviations emerge at high  $p_T$ , signaling the breakdown of the effective approximation. These findings highlight the importance of carefully accounting for kinematic effects when applying EFT-based methods to precision Higgs studies and provide a quantitative estimate of their range of validity.

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## ZnMn<sub>2</sub>O<sub>4</sub>, A BIMETALLIC OXIDE AS ACTIVE ELECTRODE FOR SUPERCAPACITOR APPLICATIONS

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The rapid population growth and technological advancement fuelled global energy demand. World is on race to develop an efficient, and sustainable energy storage solutions. Amongst the available technologies, supercapacitors have emerged as promising devices, bridging the gap between conventional capacitors and batteries. Supercapacitors exhibit higher energy and power densities, with long cycle life, low maintenance requirements and enhanced safety compared to conventional systems. Transition bi and tri metal oxides, owing to their multiple oxidation states, rich redox chemistry and high theoretical capacitance values have garnered much attention for development of supercapacitor electrodes.

In this research, ZnMn<sub>2</sub>O<sub>4</sub>, a bimetallic oxide with a spinel crystal structure, has been synthesized as the active electrode material using a facile co-precipitation method followed by thermal treatment at varying calcination temperatures. The material was thoroughly characterized using a combination of structural and electrochemical techniques, including X-ray diffraction (XRD), UV-Visible (UV-Vis) spectroscopy, Cyclic Voltammetry (CV) and Electrochemical Impedance Spectroscopy (EIS). Each technique provided insights into phase composition, crystallinity, band gap, charge storage behaviour and resistance characteristics.

The study highlights the effect of calcination temperature on the crystallite size, lattice parameters and electrochemical performance of ZnMn<sub>2</sub>O<sub>4</sub>. Specific capacitance is found to have maximum value of 139.87 F/g at 10 mV/s, revealing pseudocapacitive behaviour and good rate capability. The results demonstrate that ZnMn<sub>2</sub>O<sub>4</sub> electrodes can significantly enhance supercapacitor performance.

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## Strategic Cobalt-Chromium Co-Doping in MoS<sub>2</sub> shows Synergistic Enhancement of Electrochemical Performance for High-Capacity Supercapacitor Electrodes

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The increasing demand for advanced energy storage systems has stimulated significant research interest in developing electrode materials with enhanced charge storage capability and excellent long-term cycling stability. Molybdenum disulfide (MoS<sub>2</sub>), a layered transition metal dichalcogenide (TMD), has attracted considerable attention in recent years owing to its unique layered structure and intrinsic pseudocapacitive characteristics [1]. However, the practical electrochemical performance of pristine MoS<sub>2</sub> is limited by its low electrical conductivity and relatively fewer electrochemically active sites. These limitations can be effectively addressed through transition metal doping, which improves conductivity and enhances electrochemical activity [2].

In the present work, Cr-Co co-doped MoS<sub>2</sub> was synthesized using a facile hydrothermal method with varying dopant concentrations (1, 3, and 5 mol%) to enhance its electrochemical performance. Additionally, the study demonstrates the use of a cost-effective stainless-steel (SS) substrate, highlighting its potential for scalable and practical

applications. X-ray diffraction (XRD) and Raman spectroscopy confirmed successful dopant incorporation, phase integrity, and lattice strain modification induced by Cr–Co co-doping. The optimally doped MoS<sub>2</sub>–3C electrode exhibited a high specific capacitance of 678.24 F g<sup>-1</sup>, nearly three times higher than pristine MoS<sub>2</sub> (222.84 F g<sup>-1</sup>). Furthermore, the energy density increased by approximately 51%, rising from 42.54 Wh kg<sup>-1</sup> for pristine MoS<sub>2</sub> to 64.21 Wh kg<sup>-1</sup> for MoS<sub>2</sub>–3C. Electrochemical impedance spectroscopy (EIS) revealed a significant reduction in both solution resistance and charge transfer resistance to 4.82 Ω and 24.20 Ω, respectively, compared to 37.70 Ω and 35.84 Ω for the undoped electrode. These findings demonstrate that rational Cr–Co co-doping, combined with a low-cost SS substrate, effectively overcomes the intrinsic limitations of MoS<sub>2</sub> and enhances its suitability for high-performance supercapacitor applications.

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## Electronic and Magnetic Phase Transitions Induced by External Magnetic Field and Hund's Coupling in the Spin-1/2 Falicov–Kimball Model on a Triangular lattice

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Numerical and Monte-Carlo simulation methods are employed to study the spin-1/2 FalicovKimball model on a triangular lattice in the presence of external magnetic field and Hund's coupling. At small Coulomb correlation, the system exhibits a magnetic-field driven metal–insulator transition accompanied by a change in ground state configurations from segregated to Neel-ordered regular, quasi-regular, and mixed phases along with significant variation in the magnetic moments of localized and itinerant electrons at various chosen values of Hund's coupling. While at high Coulomb interaction, the system remains insulating and no metal–insulator transition is observed with external magnetic field. These results of tunability of electronic and magnetic properties can be used to create electric and magnetic sensors and high energy storage devices.

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## Role of High Entropy Alloy in Hydrogen storage

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Current environmental issues such as global warming and climate change are largely originated by our traditional energy sources. Around 80% of global energy still provided by fossil fuels and by product of fossil fuels leads to temperature rising of earth. So, humanity needs some advance energy sources like hydrogen energy which solve the problem of global warming. Unlike fossil fuels, the only by product of hydrogen energy is water which makes a clean solution to global warming and reduces the dependency on fossil fuels. Hydrogen offers

a much higher energy density approx. 120MJ/Kg compared to conventional energy source, which reduces the dependency on fossil fuels. The commercial use of hydrogen energy depends on several factors such as, hydrogen generation, hydrogen storage and hydrogen fuel cells which decide that hydrogen energy is efficient and safe for society or not. Among these, hydrogen storage is one of the most important factors because it directly affects the transportation of hydrogen gas and its use in vehicle for power. Hydrogen storage is possible in all phases of hydrogen gas but solid hydrogen storage is more safe and cheap for society because gaseous form of hydrogen storage needs storage tank of advance material to bear high pressure (691 atm), which makes it very expensive. Liquid hydrogen storage requires very high pressure and extremely low temperature conditions that are very difficult to maintain on a large scale.

Over time extensive research has been conducted for solid hydrogen storage including metal hydrides, carbon based materials, and chemical hydrides etc. However, since the discovery of high entropy alloy (HEA) in 2004 by Brian Cantors much of research focus is shifted towards HEA based hydrogen storage materials. HEAs exhibit unique properties such as high entropy effect, sluggish diffusion effect, lattice distortion effect, and cocktail effect. These properties enhance mechanical strength, stabilization of material at high temperature, improve hydrogen storage and optimize alloy performance, making HEAs highly promising candidates of hydrogen storage applications.

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## **Influence of intense magnetic fields on the cooling of neutron stars**

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The configuration of the magnetic field is a crucial factor in determining its effects on the internal composition and structure of neutron stars (NS). In this study, we enhance our understanding of the emission rate of observable axions-hypothetical particles that may provide insight into viable dark matter (DM) candidates resulting from the cooling of NS. We analyze the influence of the magnetic field by solving the Tolman–Oppenheimer–Volkoff equations. Our approach incorporates a radially distance-dependent magnetic field and the maximum possible strength of the central magnetic field. We assume that the nucleon–nucleon bremsstrahlung process occurs within the core of a spherically symmetric, strongly magnetized NS. The presence of a strong magnetic field significantly alters both the energy spectrum of axions and the flux of photons originating from axion-photon conversion. Notably, our results exhibit distinct features when the spectrum produced through the Bremsstrahlung process is far more pronounced when magnetic field is present, exceeding the corresponding emission in the non-magnetized configuration across the possible axion masses. We conclude that incorporating magnetic fields into the various axion production processes is essential for a comprehensive understanding of the physics underlying axionic DM, as modeled with the NS Cooling code.

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## **Bio-Waste–Derived Activated Carbon via In Situ Fabrication from *Desmostachya bipinnata* for Advanced Supercapacitor Applications**

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In the present work, we demonstrate a sustainable and cost-effective strategy for the synthesis of highly capacitive activated carbon (AC) derived from bio-waste Kusha grass (*Desmostachya bipinnata*) through a chemical treatment process followed by KOH activation. The successful formation of few-layered activated carbon was systematically confirmed using X-ray powder diffraction (XRD), transmission electron microscopy (TEM), and Raman spectroscopy, revealing its structural and morphological characteristics.

Furthermore, the chemical bonding environment and functional groups present in the as-prepared material were analyzed using Fourier transform infrared (FTIR) spectroscopy and UV-visible spectroscopy. The surface area, pore size distribution, and porosity of the synthesized AC were evaluated using the Brunauer-Emmett-Teller (BET) method, indicating a highly porous structure favorable for electrochemical applications.

The electrochemical performance of the synthesized activated carbon was investigated using cyclic voltammetry (CV) and galvanostatic charge-discharge (GCD) techniques, with primary emphasis on GCD measurements due to their greater reliability and accuracy for evaluating capacitive behavior. The as-synthesized AC electrode delivered a high maximum specific capacitance of  $218 \text{ F g}^{-1}$  within a stable operating potential window ranging from  $-0.35$  to  $+0.45 \text{ V}$ . In addition, the electrode exhibited an impressive energy density of approximately  $19.3 \text{ Wh kg}^{-1}$  and a power density of around  $277.92 \text{ W kg}^{-1}$  within the same voltage range.

Moreover, the activated carbon electrode demonstrated excellent electrochemical stability, retaining a substantial fraction of its initial capacitance even after 5000 charge-discharge cycles. The fabricated supercapacitor device also maintained high energy and power densities at increased charge-discharge rates, highlighting its robust rate capability and superior cycling stability. These outstanding electrochemical properties can be attributed to the optimized porous architecture, large surface area, and efficient ion transport pathways of the Kusha grass-derived activated carbon.

Consequently, the bio-waste Kusha grass-derived activated carbon (DP-AC) emerges as a highly promising electrode material for next-generation supercapacitor applications. This study not only presents a simple and innovative approach for converting agricultural bio-waste into high-value carbon materials but also underscores its significant potential for large-scale implementation in electrochemical energy storage systems. We envision that this sustainable synthesis route will contribute to the development of eco-friendly and high-performance electrode materials, thereby expanding their practical applicability in advanced energy storage technologies.

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## Effect of Film Thickness and Thermal Treatment on the Optical and Electrical Properties of Selenium Thin Films

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Selenium (Se) thin films of thickness 40–100 nm were deposited by thermal evaporation to study the effect of thickness and thermal treatment on their optical and electrical properties. Optical results show that increasing thickness reduces the optical band gap, while thermal treatment causes a red shift in the absorption edge, indicating improved structural ordering. Electrical measurements of the 100 nm film show temperature-dependent conductivity. At room temperature, conductivity is low and nearly linear with voltage (ohmic behavior). At  $80^\circ\text{C}$  and  $100^\circ\text{C}$ , conductivity increases significantly (up to  $\sim 10^{-8} \Omega^{-1}\text{m}^{-1}$ ) and shows nonlinear behavior at higher voltages, indicating trap-controlled space-charge-limited conduction. The results confirm thermally activated charge transport and reduced defect states after heating.

These findings demonstrate that thickness control and thermal treatment effectively tune the optoelectronic properties of selenium thin films for device applications.

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## Thermal characterization of stones formed in human body

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The formation of stones in the human body, such as gallbladder and kidney, is a painful medical condition; however, their thermal stability and phase behavior remain insufficiently explored. Understanding the thermodynamic properties of such bio-materials can provide valuable insights about formation mechanisms. In the present study, a comparative thermal characterization of gallbladder and renal stones was carried out using Differential Scanning Calorimetry (DSC) over the temperature range of 20 °C to 200 °C at a heating rate of 10 °C/min. The heating thermograms revealed distinct endothermic peaks corresponding to crystal-isotropic phase transitions in both samples. Thermodynamic properties like enthalpy and entropy changes were studied for these stone samples. The results demonstrate that DSC is an effective technique for distinguishing the thermal characteristics of biological stones and may contribute to a better understanding of their composition, stability, and formation processes.

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## Artificial Intelligence in Diabetic Wound Healing and Future Perspectives

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Modern healthcare has seen a revolution thanks to artificial intelligence (AI), especially in the area of wound care. Manual measures and subjective visual judgment are common components of traditional wound assessment techniques, which can result in inconsistent results, delayed diagnosis, and increased clinical burden. Personalized treatment planning, tissue categorization, infection prediction, automated picture analysis, and real-time wound monitoring are all made possible by AI-driven techniques like as machine learning and deep learning algorithms. AI has the ability to completely transform the treatment of wound healing, notwithstanding obstacles like data privacy, model generalization, and legal restrictions.

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## Facile Synthesis of Graphitic Carbon Nitride and Its Photocatalytic Efficiency in Methylene Blue Degradation

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Graphitic carbon nitride (g-C<sub>3</sub>N<sub>4</sub>) has emerged as a promising metal-free photocatalyst due to its suitable band gap, chemical stability, and visible-light responsiveness. In this study, g-C<sub>3</sub>N<sub>4</sub> was synthesized via a simple and cost-effective thermal polymerization method using urea as a nitrogen-rich precursor. The synthesis was carried out by calcining urea at elevated temperatures in a muffle furnace, leading to the formation of layered graphitic carbon nitride through condensation and polymerization processes. The structural and morphological properties of the synthesized material were characterized using techniques such as XRD, FTIR, and UV-Vis spectroscopy, confirming the successful formation of g-C<sub>3</sub>N<sub>4</sub> with a typical graphitic structure and optical band gap in the visible region. The synthesized g-C<sub>3</sub>N<sub>4</sub> is used as photocatalyst for the degradation of Methylene blue dye under visible light irradiation. The results demonstrated significant degradation efficiency, attributed to effective visible-light absorption and generation of electron-hole pairs. The study highlights that urea-derived g-C<sub>3</sub>N<sub>4</sub> is an efficient, environmentally friendly, and sustainable photocatalyst for wastewater treatment applications.

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## Electronic and Magnetic Phase Transitions Induced by External Magnetic Field and Hund's Coupling in the Spin-1/2 Falicov-Kimball Model on a Triangular lattice

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Numerical and Monte-Carlo simulation methods are employed to study the spin-1/2 Falicov-Kimball model on a triangular lattice in the presence of external magnetic field and Hund's coupling. At small Coulomb correlation, the system exhibits a magnetic-field driven metal-insulator transition accompanied by a change in ground state configurations from segregated to Neel-ordered regular, quasi-regular, and mixed phases along with significant variation in the magnetic moments of localized and itinerant electrons at various chosen values of Hund's coupling. While at high Coulomb interaction, the system remains insulating and no metal-insulator transition is observed with external magnetic field. These results of tunability of electronic and magnetic properties can be used to create electric and magnetic sensors and high energy storage devices.

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## Lessons from Nature: Strategies for Self-Cleaning Surfaces through Superhydrophobicity and Beyond

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Nature acts as a remarkable artist, creator, and decorator, offering profound insights into the mechanisms behind natural phenomena. One of its most fascinating expressions is the self-cleaning ability of plant surfaces, which arises from the combined effects of surface wettability and hierarchical structure. In this work, we examine how micro to nanoscale surface textures regulate wetting states and adhesion, producing a spectrum from low adhesion to high adhesion superhydrophobicity. Fully grown and healthy leaves from four plant species, namely Kalanchoe, Ziziphus, Mesua, Litchi, and sword lily, are selected as natural model systems that exhibit diverse surface morphologies and wetting responses. We investigate droplet impact

dynamics on these low and high adhesion superhydrophobic leaf surfaces, capturing behaviors that range from rolling and sliding to bouncing and jumping. These distinct responses originate from the balance between inertial, capillary, and adhesive forces, and are strongly influenced by multiscale surface roughness and chemical composition. The study highlights how nature tailors surface functionality through structural design to achieve efficient self-cleaning and liquid mobility. The insights obtained from these natural prototypes provide valuable guidelines for designing engineered surfaces with controlled wettability and droplet transport characteristics. Such understanding has direct implications for applications in microfluidic systems, anti-icing technologies, and greener pesticide spray management, where minimizing liquid retention and enhancing droplet removal are essential for performance and sustainability.

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## Advanced Rare Earth Doped Upconversion Materials: Innovation Toward Integrated Multifunctional Platforms

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Rare earth ion doped frequency up-conversion (UC) materials have attracted significant attention for various applications, such as light-emitting devices, energy conversion, optical heating, photocatalysis, temperature sensing, surface-enhanced Raman spectroscopy (SERS), and biomedical imaging [1–5]. The UC phenomenon is a well-established approach for converting near-infrared (NIR) light into visible light [1]. In practice, multiphoton absorption and energy-transfer processes are responsible for the generation of visible luminescence. The multifunctional behavior of these UC materials is currently a hot topic among researchers working in the field of lanthanide incorporated nanostructured optical materials. Here, the synthesis and characterization of few UC materials based on Er/Tm/Nd ions as activators are discussed. Fluorescence intensity ratio (FIR) based tuning, utilizing two thermally coupled energy levels or Stark sublevels, has been demonstrated for non-contact high temperature optical sensing and laser-induced optical heating. A facile preparation of a SERS substrate based on upconverting phosphors for the detection of harmful dye (RhB) is also reported [2]. Various radiative and non-radiative pathways have been investigated to understand the luminescence mechanism. The experimental studies carried out on these rare earth doped UC materials demonstrate their multifunctional applications.

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## Integrated silicon photonics based Multi-parametric sensing platform

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The emerging customized point of care (POC) and home health care diagnostic applications demand the development of highly integrated, compact, smart and low cost biosensors. The recent advances in the integrated silicon photonics have stimulated research around the globe on the development

of such label free chemical and bio-sensing platform using photonic resonant structures. Conventional sensors produce a single signal which responds to different parameters such as refractive index change, molecular binding, temperature gradient, etc., necessitates the requirement of several iterations and intensive post measurement processing to decouple molecular information from the modulated signal, or the requirement of separate sensor elements for each parameter, which makes the system more complex and costly. So it is highly desirable for a biosensor to have multi parametric functionality and we propose a multi parametric sensing schemes based on grating waveguide arrays in silicon - on - insulator (SOI) optical bench platform.

In this approach, the grating waveguide (GWG) will act as sensor as well as detector also. The molecular binding will induce strain on the sensor surface which will modulate the grating period resulting the shift of only the band edge transmission. So in the proposed device the strain effect can be harnessed by suspending the waveguide grating and hence the same device can generate two sensitive signals simultaneously, each carries unique information about the molecular binding reaction providing a means for accurate quantitative and qualitative assessment without the need for multiple iterations and laborious post measurement processing.

We have fabricated suspended Silicon grating waveguide using standard CMOS fabrication techniques. The differential tuning of band edge transmissions in a phase shifted waveguide grating has been demonstrated using a mathematical model based on transfer matrix method and the experimental results show the presence of multiple transmission modes, which can be tuned selectively by altering different parameters such as surrounding refractive index or molecular binding.

Reference:

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