Announcing the Final Examination of Premadasage Kithsiri Kapila Kumarasinghe for the degree of Doctor of Philosophy in Physics
Date: March 14, 2025
Time: 2:30 p.m.
Room: PSB 160
Dissertation title: Study of the superconducting and normal states properties of topological nodal-line semimetals.

Abstract:
Topologically protected quantum computation is getting great interest due to its potential use in creating fault-tolerant quantum computers. Using quasiparticle excitations known as non-Abelian anyons, which obey non-Abelian braiding statistics, is the way to perform topological quantum computation. A topological superconductor has protected gapless states on its boundaries while maintaining a superconducting gap in the bulk, and predicted to host Majorana fermions which are non-Abelian anyons. Although several theoretical models propose systems with non-Abelian anyons, $p_x + ip_y$ wave superconductors in which vortices exhibit non-Abelian braiding statistics is one of the most realistic physical systems. Realizing physical systems with non-Abelian anyons is one of the frontiers in recent theoretical and experimental research works. Therefore, in this thesis, we studied predicted superconducting topological nodal-line semimetals to realize possible topological superconductivity, flat energy bands and the effect of spin orbit coupling, in the normal and superconducting states.

To investigate the topological nature and superconductivity, we synthesized $Sn_{0.15}NbSe_{1.75}$ single crystals using the self-flux method and studied the normal and superconducting state properties of $Sn_{0.15}NbSe_{1.75}$ (T_c = 9.5 K) using soft-point-contact spectroscopy. We observe asymmetric double peaks in the normal state differential conductance dI/dV due to the Fano resonance as a result of quantum interference between two distinct tunneling paths of transmitting electrons into flat energy bands and dispersive bands. Hybridization between these bands below the hybridization temperature T_{hyb} = 23 K is realized according to a phenomenological double Fano resonance model. A pseudogap below a characteristic temperature T_{PG} = 6.8 K is also observed due to the hybridization between these bands. We observe an unusual linear in T behavior in upper critical field from $0.4T_c$ to $0.01T_c$, indicating a possible exotic superconducting state. Our results indicate the presence of surface flat energy bands and hybridization between the surface flat bands and the bulk bands in $Sn_{0.15}NbSe_{1.75}$.

To clarify the effect of spin orbit coupling on superconductivity, we studied the normal and superconducting state properties of $Pb_{1-x}Sn_xTaSe_2$ ($0 \le x \le 0.23$) single crystal synthesized by chemical vapor transport technique. Substituting Pb with Sn enhances the superconducting transition temperature T_c up to 5.1 K and also significantly increasing impurity scattering in $Pb_{1-x}Sn_xTaSe_2$. The normalized specific heat jump at T_c for x = 0 and 0.018, exceeds the Bardeen-Cooper-Schrieffer (BCS) predicted value of 1.43 for the weak-coupling superconductor. This observation indicates the possible strong-coupling superconductivity in undoped and slightly Sn-doped $PbTaSe_2$. A single-gap model cannot explain the observed specific heat jump at T_c that is smaller than the BSC value of 1.43 for moderately Sn-doped samples. A two-gap model excellently reproduces the observed specific heat data of moderately Sn-doped (x = 0.08 and 0.15) $PbTaSe_2$. Our observations suggest that the multiband effect increases the effective electron-phonon coupling strength, gives rise to an enhancement in T_c of $Pb_{1-x}Sn_xTaSe_2$.

Outline of Studies:
Major: Physics

Educational Career:
M.A. in Physics University of Mississippi, USA 2020
M.Sc. in Physics of Materials University of Peradeniya, Sri Lanka 2017
B.Sc. University of Peradeniya, Sri Lanka, 2010

Committee in Charge:
Dr. Yasuyuki Nakajima (Chair)
Dr. Richard Klemm
Dr. Madhab Neupane
Dr. Akihiro Kushima (External Committee Member)

Approved for distribution by Dr. Yasuyuki Nakajima, Committee Chair, on March 05, 2025.

The public is welcome to attend.