Chapter 6

Summary and Future Plans

6.1 Summary

In this thesis, we calculated OTOC by using different observables. For the calculation of OTOC, we consider integrable and nonintegrable periodically kicked quantum Ising spin Floquet models. In this model, we see the dynamic and saturation behavior of OTOC using single-spin, block-spin, and random observables. We also studied the forward and backward flow of the magnons by using the left and right OTOC. The flow of the magnon is considered as quantum information current and using this we proposed a quantum information diode based on magnonic crystals. The results are concluded below. The ideas of future work that is related to these results are also discussed in section 6.2.

we defined longitudinal magnetization OTOC (LMOTOC) and transverse magnetization OTOC (TMOTOC) by considering position-dependent observables in the longitudinal and transverse directions of coupling of spins, respectively. We calculate the analytical formula of TMOTOC by using the Jorden-Wigner transformation and present the exact analytical solution of TMOTOC. We do comparative study of the revival time, and speed of correlation propagation in TMOTOC and LMOTOC. After that, we will verify the phase structure of the transverse Ising Floquet system in $\tau_0 - \tau_1$ parameter space, numerically. We use the long-time average of LMOTOC as an order parameter to distinguish the ferromagnetic and paramagnetic phases.

Subsequently, we discussed the characteristic, dynamic, and saturation regimes of the LMOTOC and TMOTOC in the Floquet system with and without a longitudinal field. we present a comparative study of LMOTOC and TMOTOC in all the regions: (1) characteristic regime when it is about to grow, (2) dynamic region when it is sharply growing, and (3) saturation region when it starts to saturate. We focused on the role of integrability in all the regions of OTOC.

we used symmetric blocks of spins or random operators localized on these blocks are used as observables to study OTOC in spin chains. we choose the nonlocal block-spin observables and random observables to see the possibility of exponential growth of OTOC and exponential saturation of OTOC. We calculated OTOC in pre-scrambling and post-scrambling time regimes and analyzed the growth and saturation, respectively. OTOC with spin-block observables shows a power-law growth in both integrable and nonintegrable systems. The exponential saturation of OTOC is analyzed using the pre-scrambled random-block observables. We have explicitly derived a connection between OTOC averaged over random observables drawn from the Gaussian unitary ensemble and the operator entanglement entropy.

Later, we provide the concept of quantum information diode, *i.e.,* a device rectifying the amount of quantum information transmitted in the opposite directions. we control the asymmetric left and right quantum information currents through an applied external electric field and quantify it through the left and right OTOC. To enhance the efficiency of the quantum information diode, we utilize a magnonic crystal. A quantum information diode can be fabricated from an YIG film. This is an experimentally feasible concept and implies certain conditions: low temperature and small deviation from the equilibrium to exclude effects of phonons and magnon interactions. We find that rectification of the flaw of quantum information can be controlled efficiently by an external electric field and magnetoelectric effects.

6.2 Future plans

The OTOC, as described so far in the thesis, can serve as a reliable metric to determine if the system's dynamic behavior is chaotic or not. In particular, it allows us to study and potentially use the exotic behavior of chaotic dynamics within quantum systems. For example, quantum processors modeled over such chaotic systems shall be particularly suited for advanced searching and optimization problems in the near future.

We have calculated the dynamics and saturation of OTOC by using single spin and block spin observables in the constant field Floquet system. Growth and saturation of OTOC can also be discussed in the Floquet system with time-dependent fields. Time-dependent fields can be either periodic or linear fields. In the case of a periodic field, one can take a longitudinal field in sine form and a transverse field in the form of kicks whose amplitude of kicks varies as cosine form. In the calculation of OTOC, OTOC can consider, Single spin observables, block spin observables, and half-body observables. We expect that with time-dependent fields, there will be exponential growth of OTOC in the chaotic Ising spin systems.