The main idea of this grant is to integrate semiconductor materials and superconductors into high-quality single-crystalline layers produced using PAMBE (plasma-assisted molecular beam epitaxy). Although combining semiconductors and superconductors is not a new concept, nor is superconductor-based electronics, existing implementations have primarily relied on polycrystalline layers of aluminium or niobium deposited by sputtering onto silicon substrates. Successive oxide layers were deposited in a similar fashion, enabling the creation of Josephson junctions and other superconducting electronic components.

However, this approach differs significantly from traditional semiconductor fabrication methods, which involve growing thin, single-crystalline layers of semiconductor materials on a single-crystalline substrate, with crystallographic alignment typically matching the substrate's orientation. This method, used for silicon, GaAs, or GaN, underpins a wide array of semiconductor devices, from LEDs and semiconductor lasers to integrated circuits. To date, such a technique has not been employed for superconducting layers used in Josephson junction quantum computers, SQUID magnetometers, or single-photon detectors.

In the proposed project, we aim to use niobium nitride (NbN) as superconducting layers deposited on single-crystalline magnesium oxide (MgO) or magnesium cadmium oxide (MgCdO). These materials share the same crystal structure and have closely matched lattice constants, as shown in Figure 1. We firmly believe that advancing epitaxial growth in superconductor-semiconductor systems will open pathways for a new generation of quantum electronics. NbN has a critical temperature of 16.6 K, which allows for the use of more cost-effective dilution cooling systems based on ^{4}He rather than ^{3}He. With improvements in the quality of NbN layers, the performance parameters of the systems we develop could be enhanced, potentially leading to qubits with reduced decoherence.

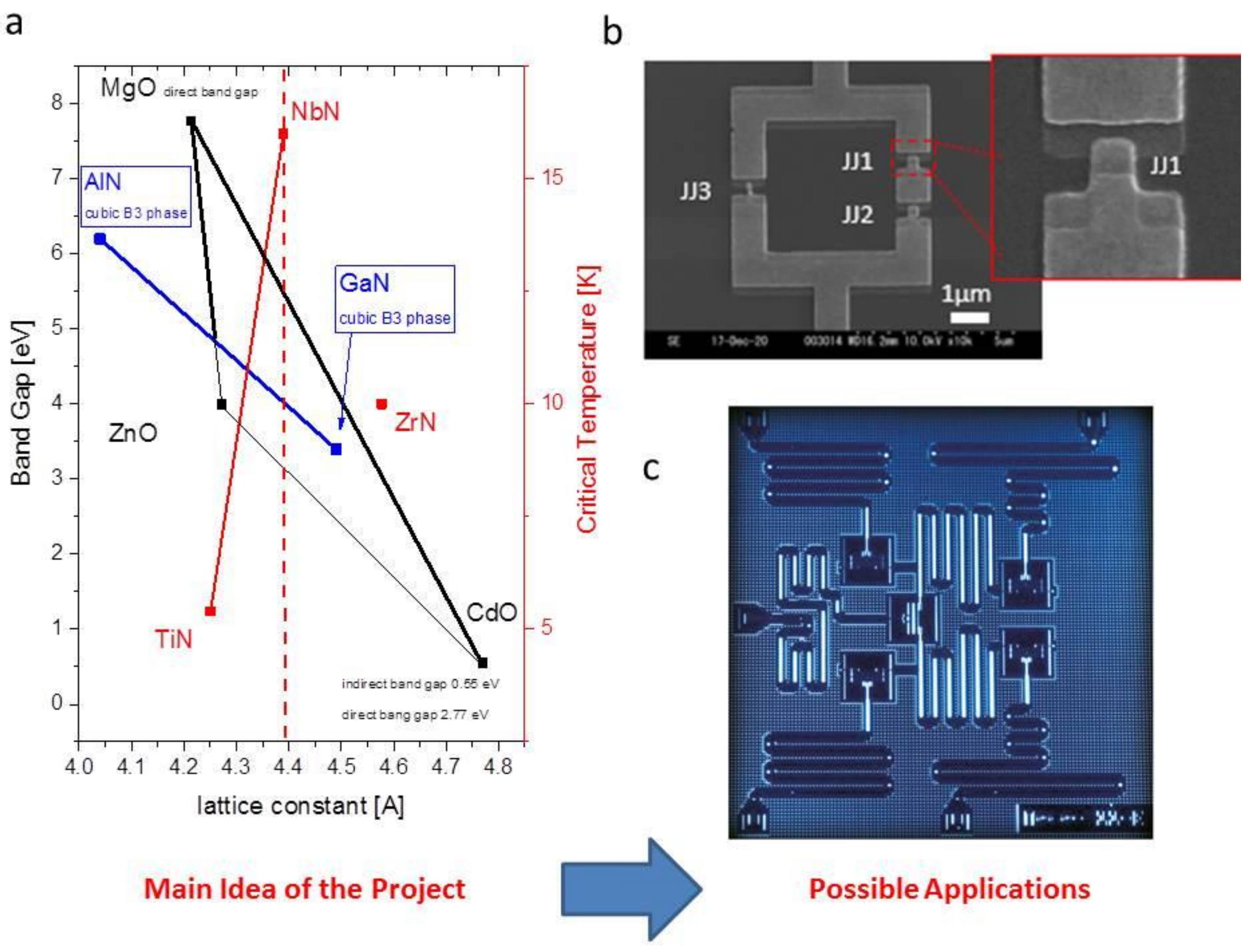

Fig. 1: (a) A graph showing the energy gap of semiconductors and the critical temperature of superconductors as a function of lattice constant. Superconducting nitrides are marked in red, cubic semiconductor nitrides in blue, and cubic semiconductors, such as MgO, MgO/CdMgO, and MgO/ZnMgO, are marked in black. (b) Photograph of a superconducting flux qubit, with 'JJ' indicating the Josephson junction. (c) IBM's QX4 five-qubit quantum computer.