Study of Acoustoelectric Interactions in α-In_2Se_3 - $LiNbO_3$ Heterostructure for Efficient RF Communication System

The growing global demand for energy is creating an urgent need for more efficient computation and communication technologies (Figure 1a) [1]. Despite vast improvements in computational efficiency, modern radio systems integrated on-chip still cannot simultaneously transmit and receive data (Figure 1b). Although circulators enable concurrent transmission and reception, conventional designs rely on magnetic fields, making them difficult to integrate with modern semiconductor technologies (Figure 1c) [2]. Acoustoelectric devices provide a promising magnet-free alternative for realizing compact and energy-efficient circulators. In this work, we explore a novel heterostructure based on α-In_2Se_3 which is a two-dimensional ferroelectric semiconductor with moderate bandgap (1.39 eV) and carrier mobility up to 3392 cm2/(V*s) [3].

This study will be carried out in three main stages. The first stage focuses on simulating the acoustoelectric device gain to optimize heterostructure dimensions based on key material properties of α-In_2Se_3, such as carrier mobility and doping concentration. The second stage involves 2D material fabrication through mechanical exfoliation and characterization of exfoliated α-In_2Se_3 flakes to evaluate practically achievable device performance (Figure 2). In the final stage, the optimized structure will be integrated into a complete device design guided by simulation results.

The simulation framework for the α-In_2Se_3–$LiNbO_3$ heterostructure was first validated against an existing InGaAs–AlScN design [4]. The proposed model exhibits higher gain in the low-frequency regime (Figure 3a). Additionally, the gain-to-power ratio (Figure 3b) indicates improved efficiency, attributed to the moderate carrier mobility of α-In_2Se_3. While higher mobility (InGaAs) can increase gain, it also leads to greater power dissipation, reducing overall efficiency. Figure 4 illustrates the impact of doping concentration on performance. Maximum gain is observed near a doping level of 10^{16} cm^{-3} (Figure 4a), whereas efficiency is higher at lower doping levels (Figure 4b). An optimal operating region is identified (Figure 4c), where both gain and efficiency are balanced. At 1 GHz, the device achieves a gain of 37.8 dB with a low power dissipation of only 0.02 mW.

Mechanical exfoliation of α-In_2Se_3 using different adhesives initially produced poor-quality flakes, prompting investigation of process parameters such as substrate baking conditions. Increasing the baking temperature from 150°C to 200°C improved flake uniformity and size, and a Design of Experiments approach will be used to further optimize yield for device fabrication.

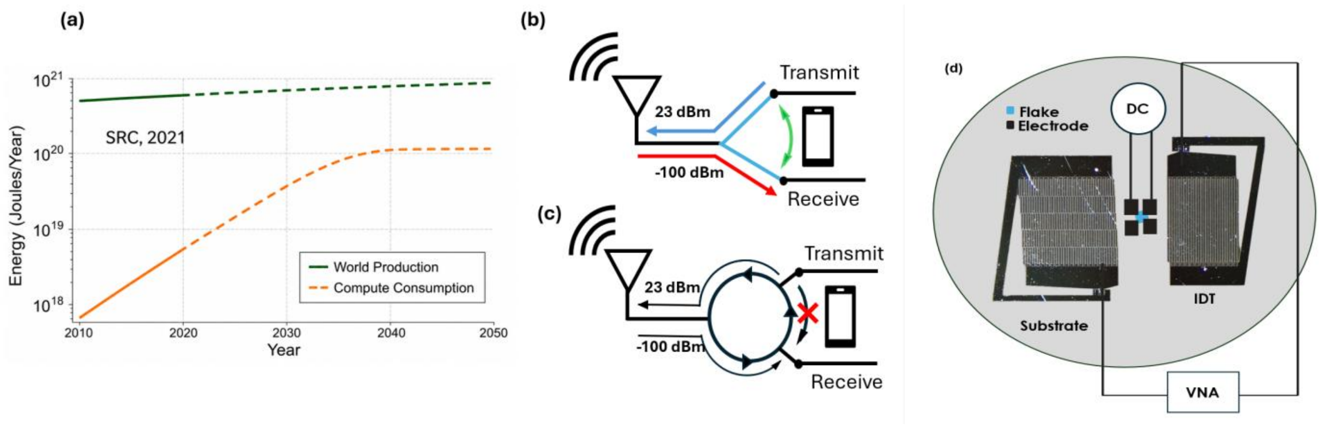


Figure 1: (a) Growth in computing energy consumption and energy production [1]. (b) Traditional radio architecture with physical switch, preventing simultaneous transmission and reception. (c) A circulator-based design enables time domain multiplexing, but use of magnetic bias makes it incompatible with CMOS integration. (d) Proposed magnet-free acoustoelectric device setup.

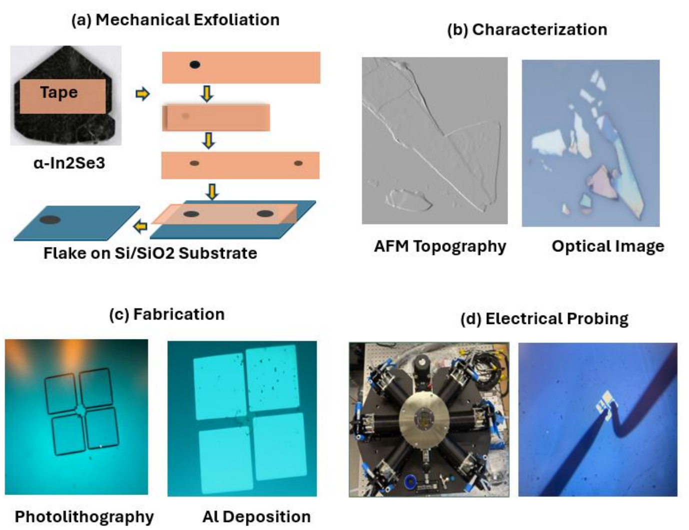
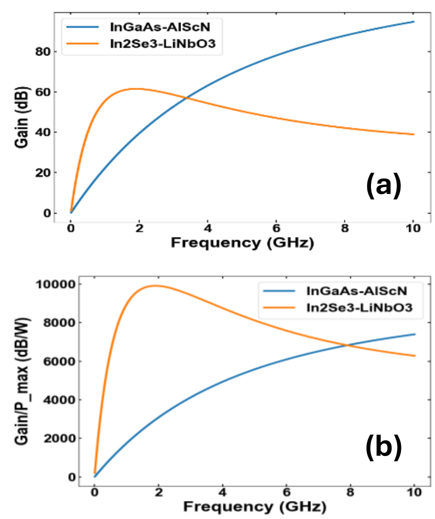


Figure 2: 2D α-In_2Se_3 Fabrication. (a) Mechanical Exfoliation, (b) Characterization of exfoliated flake using Optical and Atomic Force Microscopy, (c) Electrode fabrication, (d) Electrical probing for Hall measurement.



Constant Variables:
Width = 100 um
Length = 800 um
Thickness = 50nm
Doping=10^15 cm^{-3}

Figure 3: Comparison of the proposed In2Se3–LiNbO3 model with the existing one [4]. (a) The proposed model shows higher gain at low frequencies but decreases, (b) The gain-to-dissipated power ratio is significantly higher in our structure, indicating better efficiency.

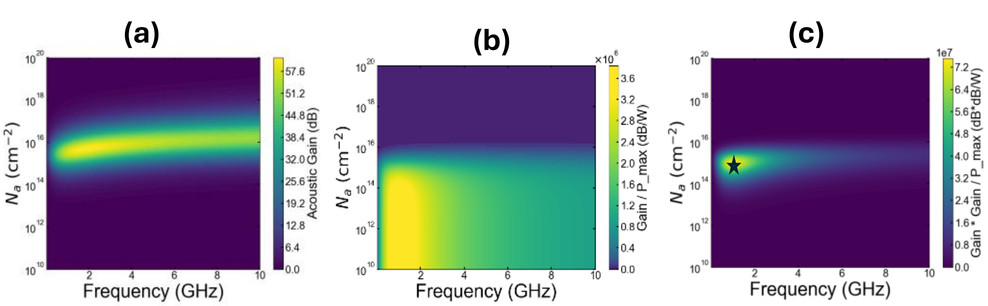


Figure 4: (a) Maximum gain occurs around a doping level of 10^{16}. (b) Although gain increases with doping, efficiency (gain-to-power ratio) is higher at lower doping levels. (c) Identifies the optimal at 1 GHz, with 37.8 dB gain and only 0.02 mW power dissipation.

References:

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