Surface Acoustic Wave Enhancement of Photocathode Quantum Efficiency

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Research of Enhancement to Photoelectric Devices Using Surface Acoustic Waves

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Dissertation Proposal directed by:
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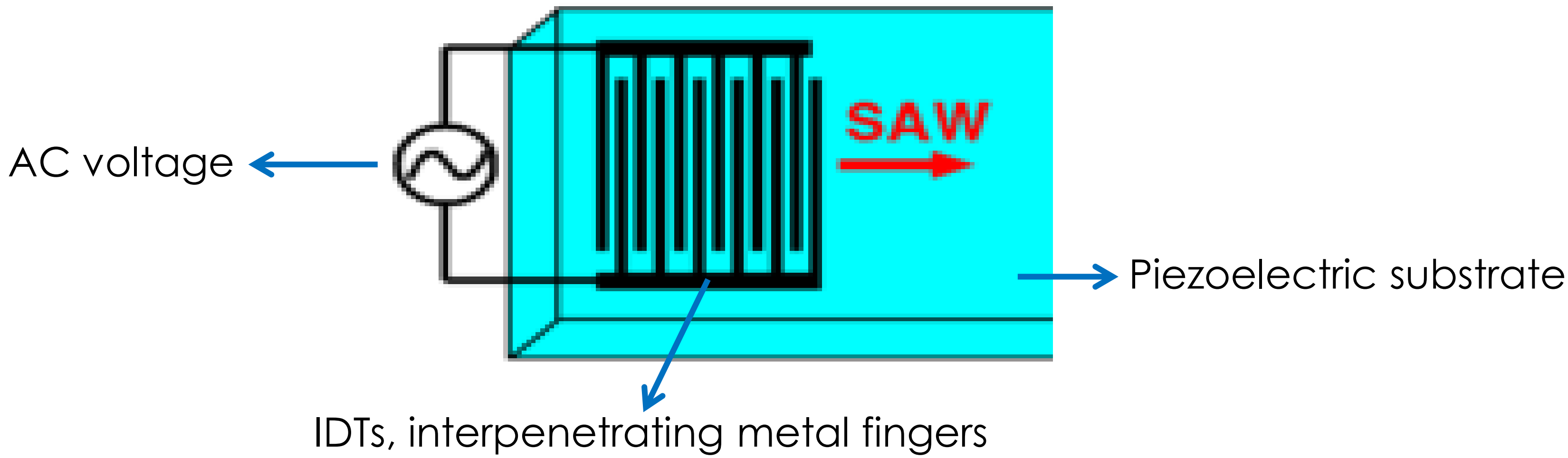
Outline

I. Introduction and mechanism
II. Preliminary Simulation Results
III. Simulations of Photocathode Application with SAWs
IV. Future Plan

I. Introduction and mechanism

Generation and properties of SAWs

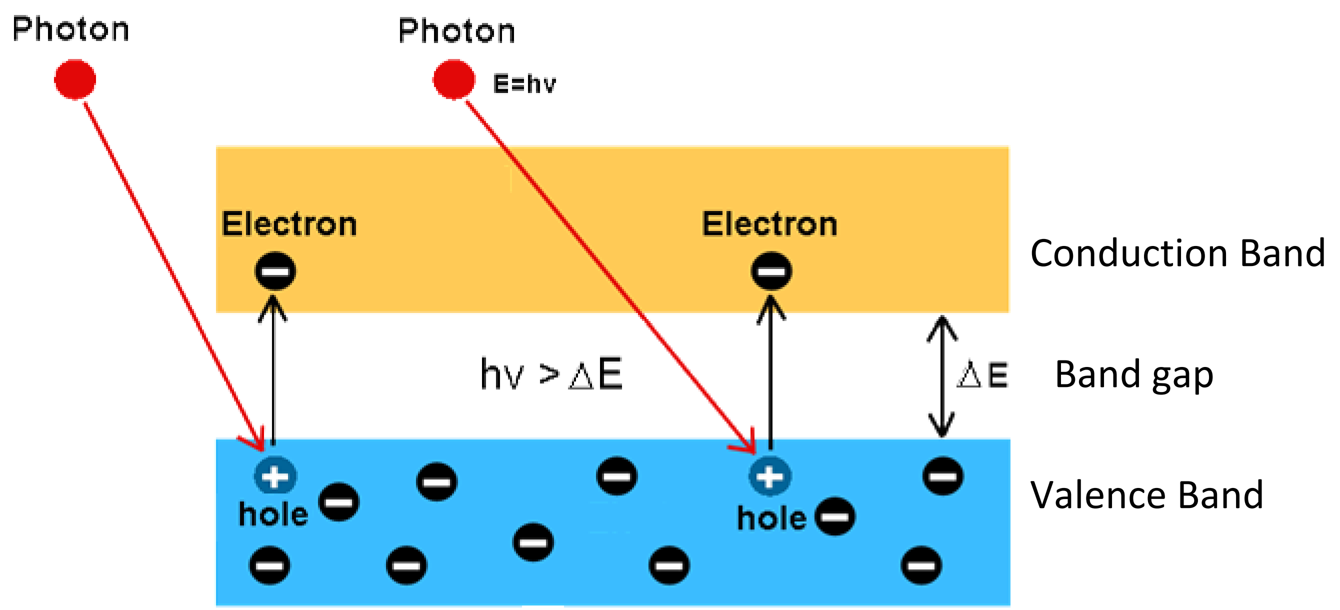
SAWs: Surface Acoustic Waves, generated by using IDTs(Interdigital Transducer) on top surface of piezoelectric material, with applied AC voltage.



$$f = v / \lambda$$

f: frequency of acoustic waves
v: propagating velocity of acoustic waves
λ: wavelength, distance between each IDT finger

Semiconductor with incident photons



- **Generation:** Incident photons(hv>ΔE) are absorbed and used to excite electrons jump across energy gap into conduction band, leaving holes in valence band.
- **Recombination:** A reverse transition that conduction band electrons jump back to valence band, and energy is released.

Changes induced by SAWs

SAWs propagating along semiconductor material surface

↓

Periodic deformation of crystal lattice

↓

Periodically modulated electric potential

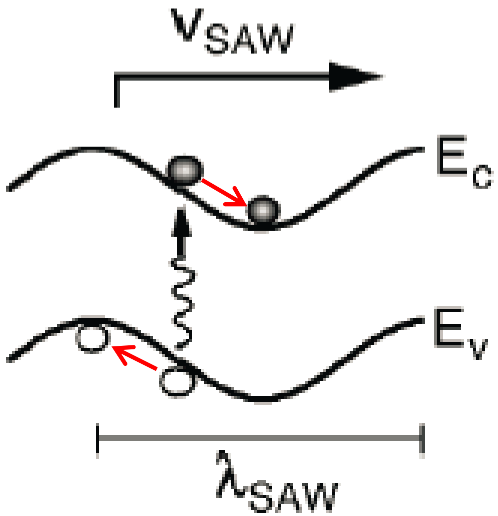
Energy bands are shifted up and down

↓

Electrons and holes are spatially separated

↓

Recombination is suppressed, and thus improve performance of photoelectric devices



Electrons are pulled to the troughs of conduction band.

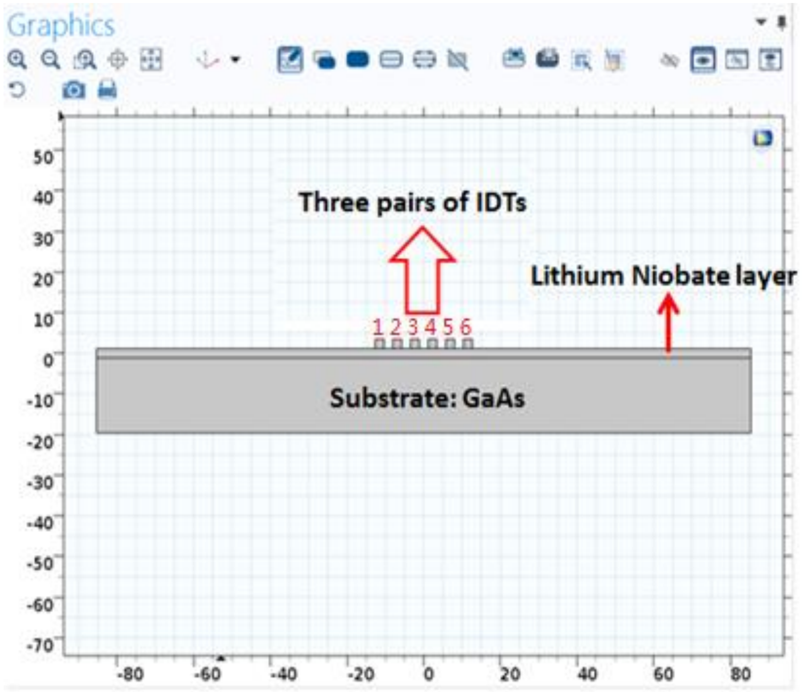
Holes are pulled to the crests of valence band.

- In this proposal, the multi-physics simulation tool COMSOL is used to build models of SAWs propagating on semiconductor material.
- Simulation results are used to verify the properties described above, and to prove that photoelectric devices are able to be enhanced via using SAWs.

II. Preliminary Simulation Results

- Generation and propagation of SAWs
- Periodical electric potential
- Band-bending effect
- Separation of electrons and holes
- Transportation of carriers

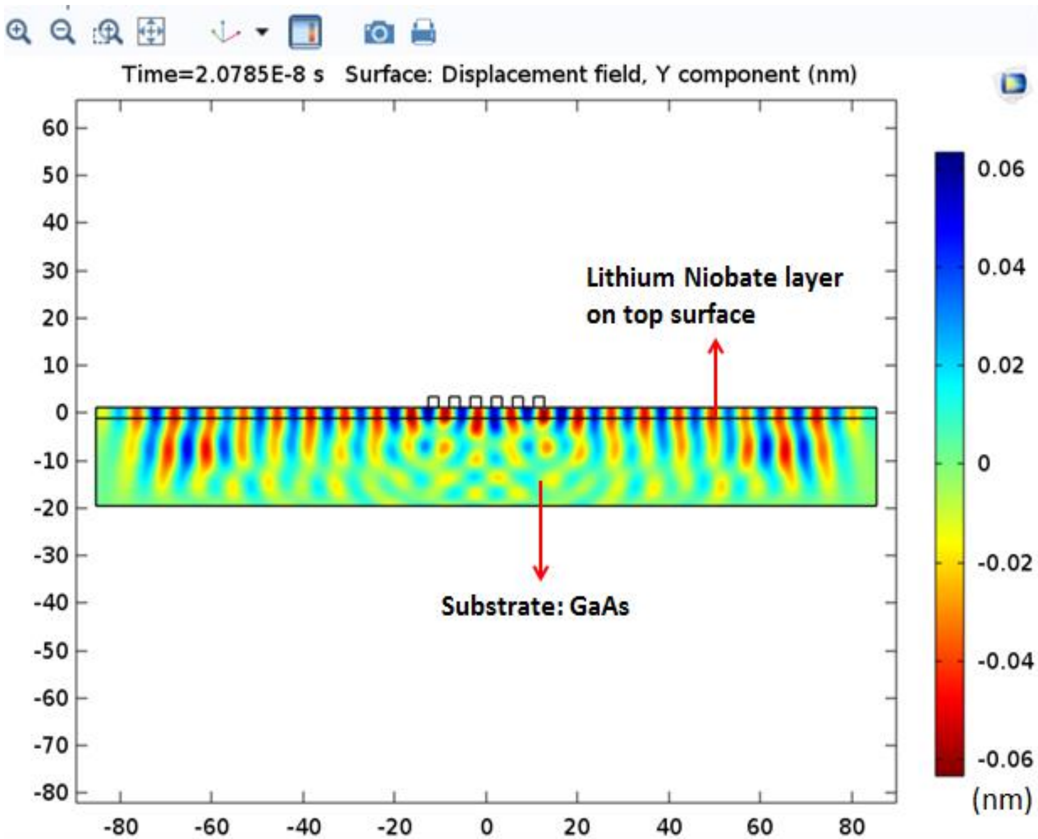
Simulation structure



- Surface acoustic waves:
  - Velocity: 3996 m/s
  - Frequency: 433 MHz
  - Wavelength: 9.2 um

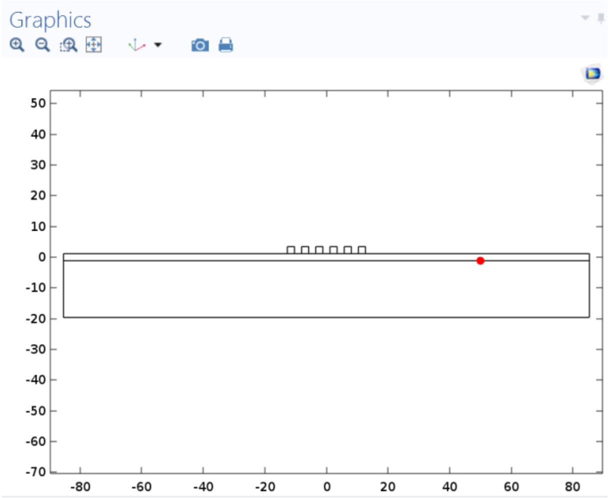
- IDTs no.2, 4 & 6 are grounded.
- IDTs no.1, 3 & 5 are applied to AC voltage: $V\_in = V_0 \times \sin(2\pi \times f_0 \times t)$
  - V_0=10V, f_0=433MHz

Generation and propagation of SAWs

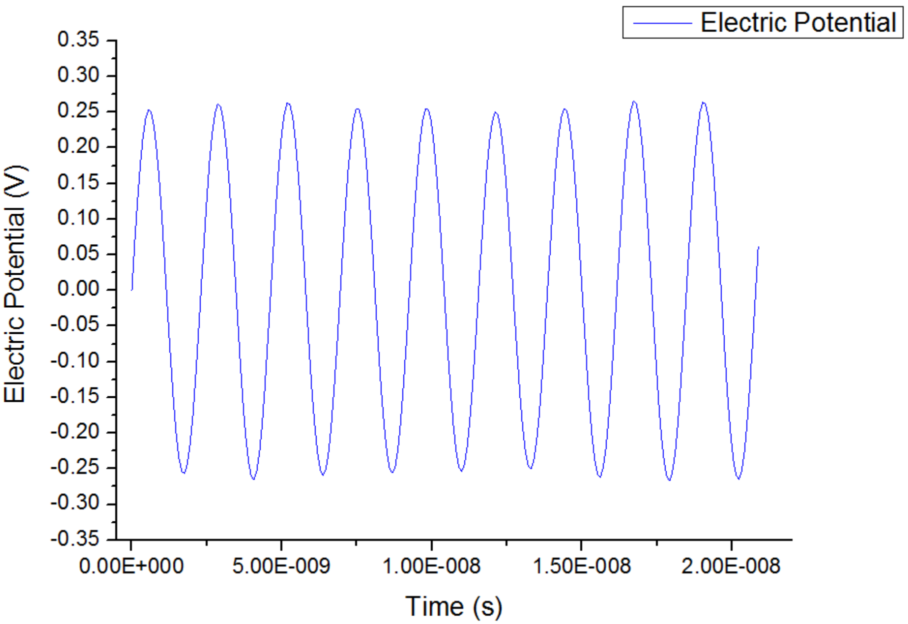


Surface deformations induced by propagating SAWs

Periodical electric potential



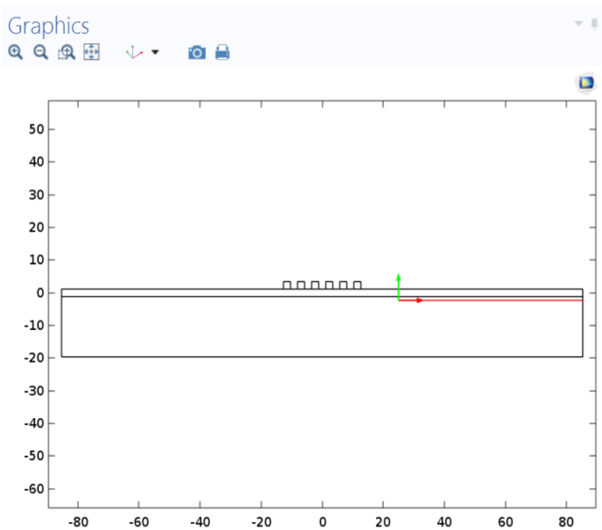
Cut-point



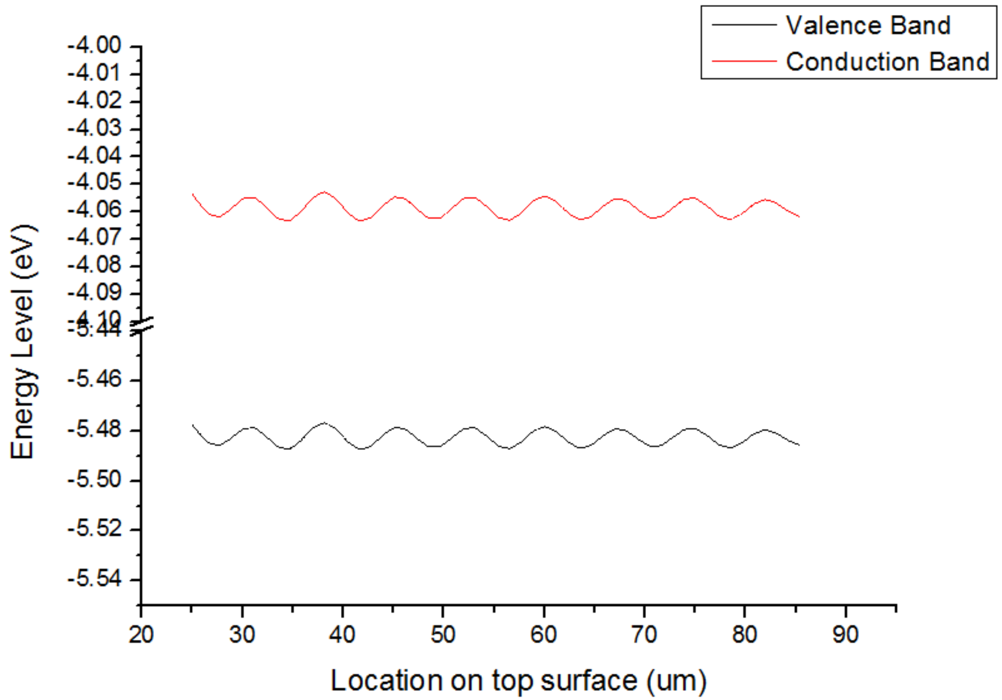
Period time of potential is 2.33E-9 s, which is equal to the period of SAWs:

$$t=1/f = 1/433\text{MHz} = 2.31\text{E-9 s}$$

Band-bending effect

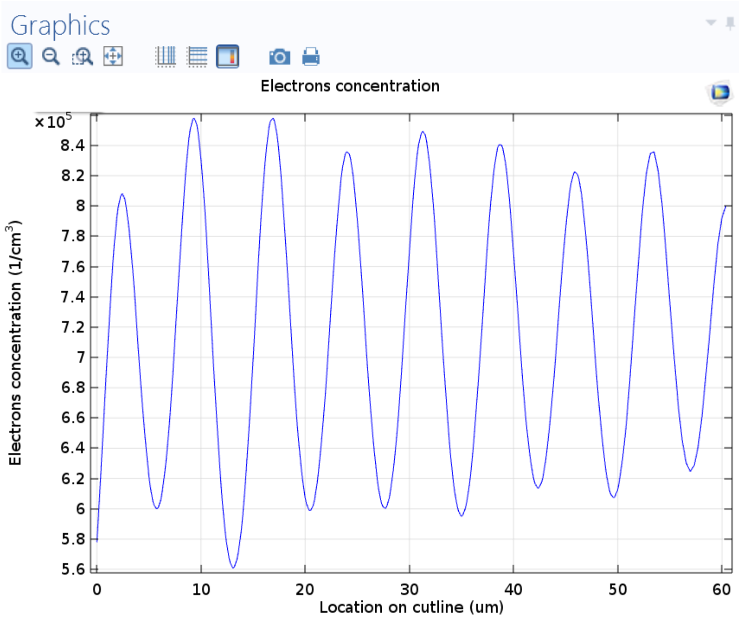


Cutline (red one)

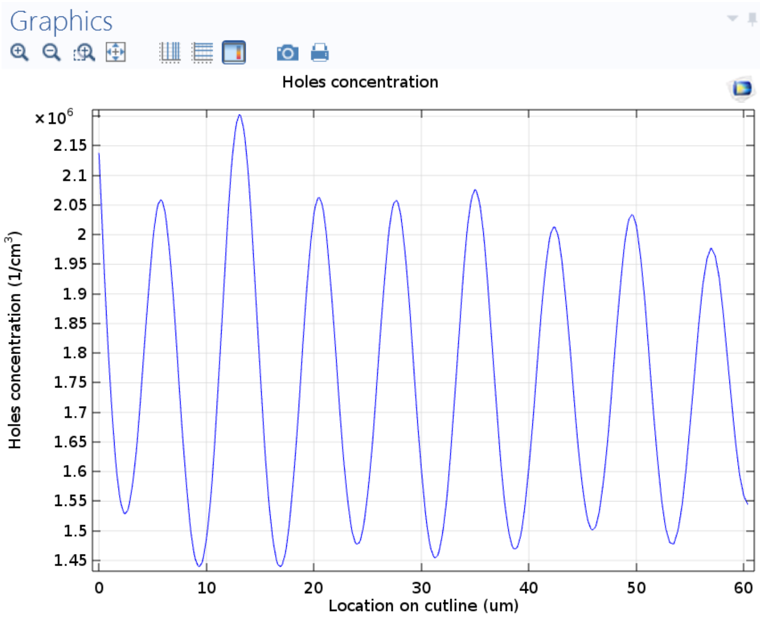


Energy bands

Separation of electrons and holes



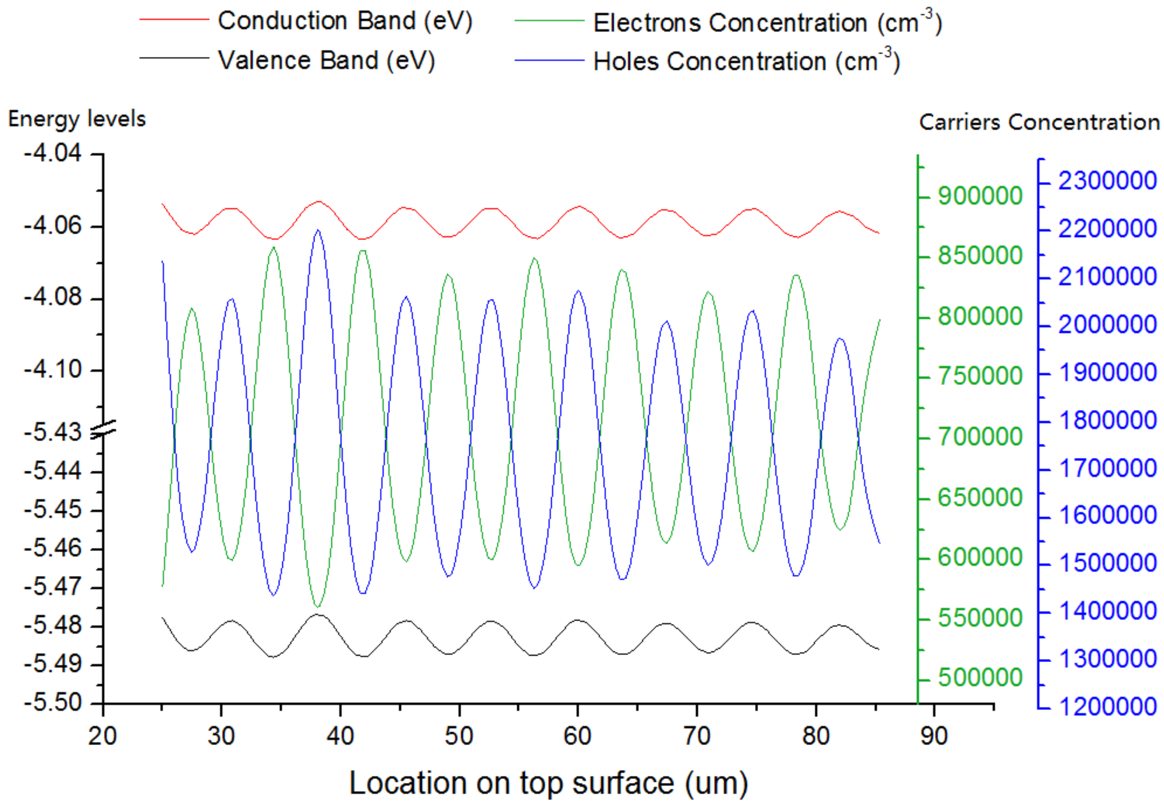
Electron concentration

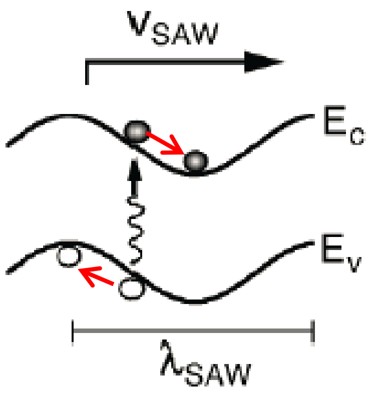


Hole concentration

- ✓ In both figures, those wave crests mean carriers are accumulating over there, and those wave troughs refer to locations where carriers are few and sparse.

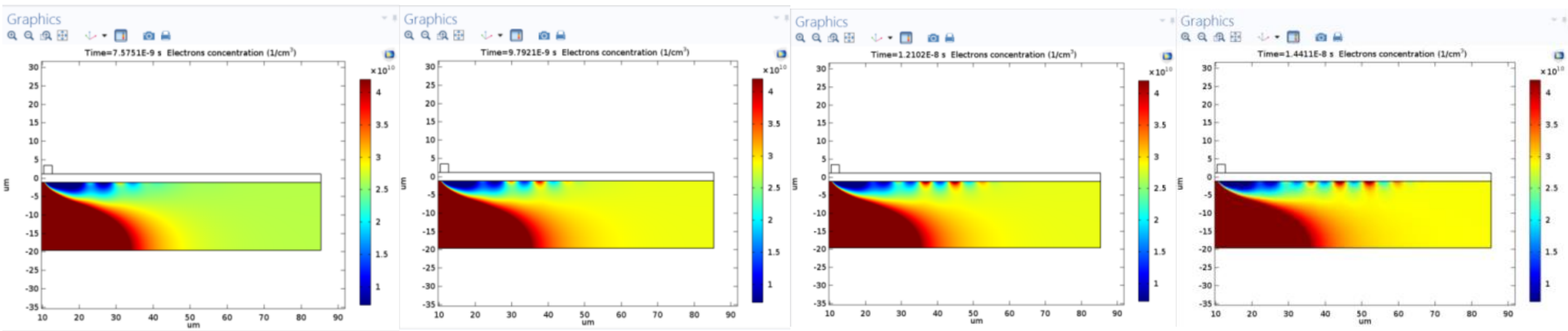
Separation of electrons and holes



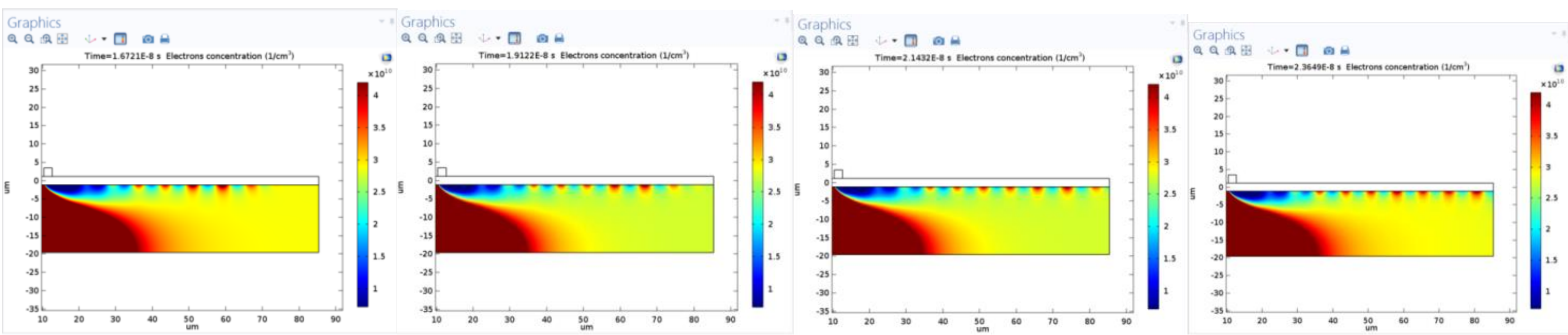


Combination of results of energy bands and carriers concentration

Transportation of carriers



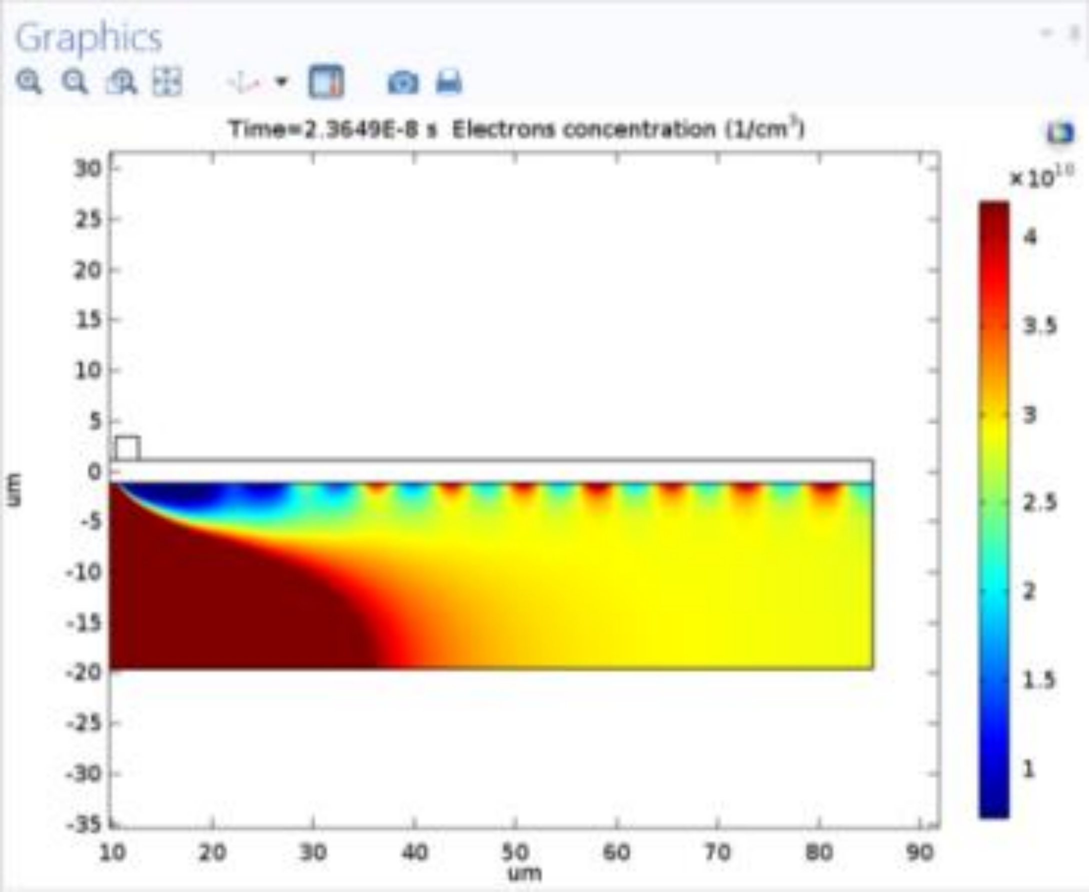
(a) t=7.6ns (b) t=9.8ns (c) t=12.1ns (d) t=14.4ns



(e) t=16.7ns (f) t=19.1ns (g) t=21.4ns (h) t=23.6ns

Process of electrons transportation by SAWs

Transportation of carriers



(h) t=23.6ns

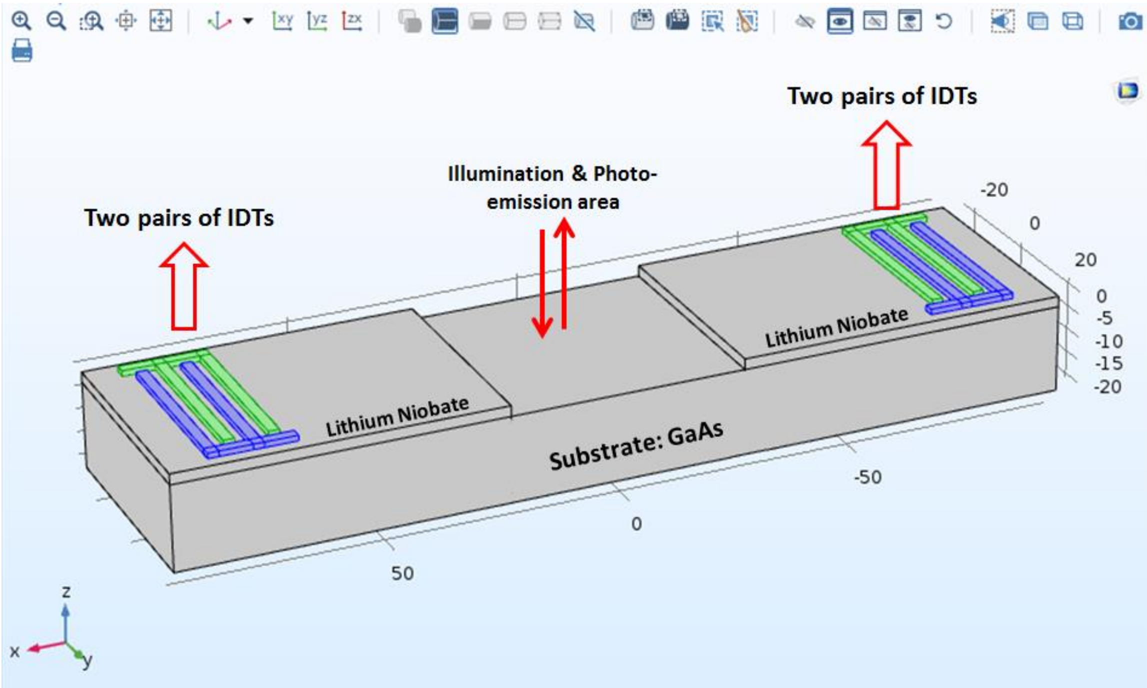
Process of electrons transportation by SAWs

III. Simulations of Photoelectric Applications with SAWs

a) Photo-cathode with SAWs

b) **Skip Today** - Photo-detector with SAWs

Photo-cathode with SAWs

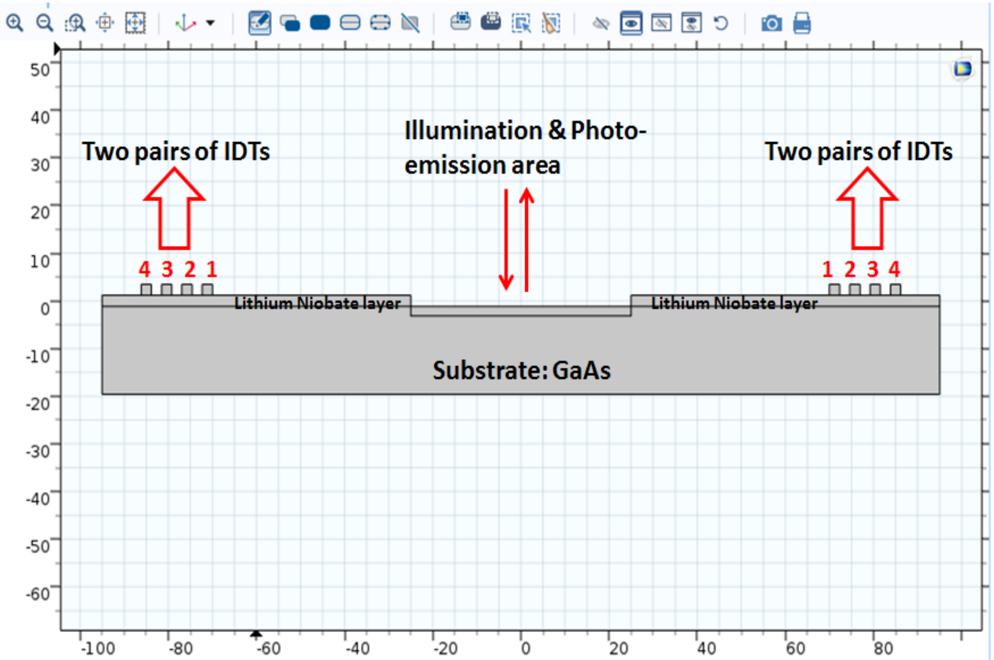


✓ **Purpose of using SAWs:**

- Lower recombination
- More electrons reach top surface for photo-emission process.

- Simulation is limited to photon absorption and concentration of electrons on top surface of GaAs in presence of SAWs.
- On top center part, Lithium Niobate layer is eliminated because this part will be used to deposit negative-electron-affinity coating layer for electrons tunneling and emission in future research steps.

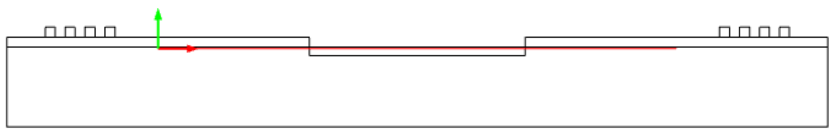
Simulation structure



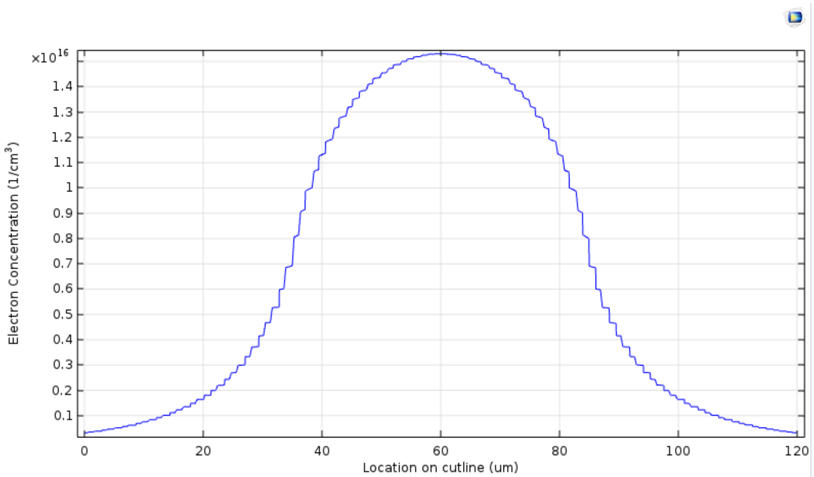
- Surface acoustic waves:
  - Velocity: 3996 m/s
  - Frequency: 433 MHz
  - Wavelength: 9.2 um

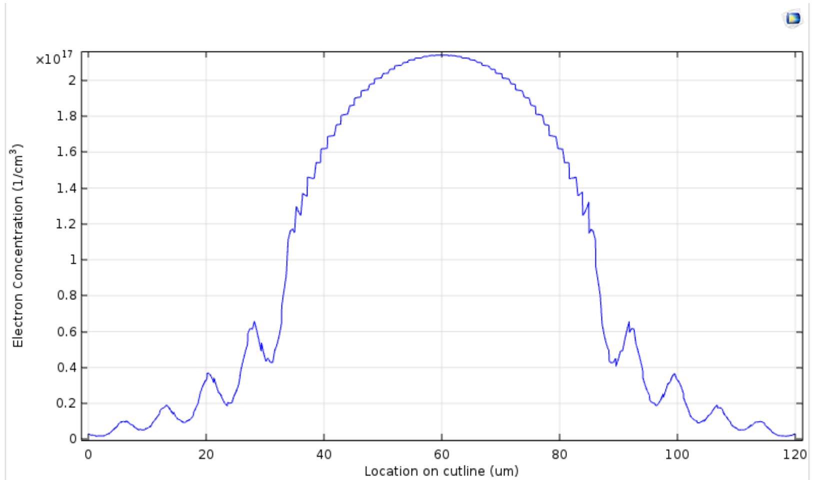
- GaAs: p-type doping concentration 1e18 cm^{-3}
- Photo-generation area: 50um × 2um, rate: 1e25 $cm^{-3}s^{-1}$
- IDTs no.1 & no.3 are grounded.
- IDTs no.2 & no.4 are applied to AC voltage: $V\_in = V_0 \times \sin(2\pi \times f_0 \times t)$
  - V_0=1V, f_0=433MHz

Simulation results



Cutline (red one)

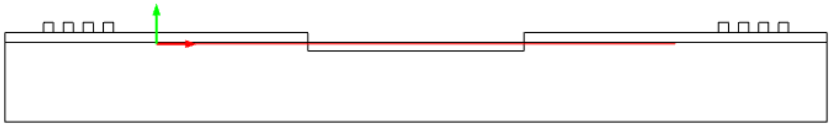




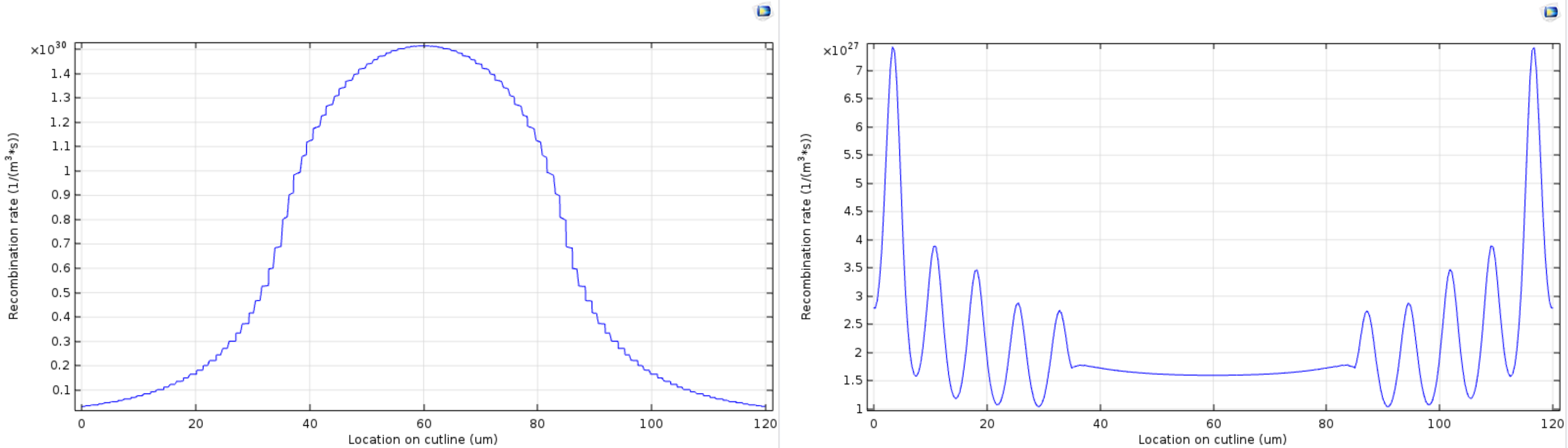
Electron concentrations extracted on cutline without SAWs (left) and with SAWs (right)

- Figures above clearly demonstrate about 14 times more electrons on top surface of photo-emission area on GaAs substrate due to the effect of Surface Acoustic Waves.

Simulation results



Cutline (red one)



Recombination rates extracted on cutline without SAWs (left) and with SAWs (right)

- Simulation results show recombination rates reduced by about 10^3 times when the Surface Acoustic Waves propagate along the surface of p-type GaAs substrate.

(a).

1. We will purchase p-type GaAs wafer as substrate. For the first stage of sample preparation, a standard cleaning process is applied with Acetone and IPA. (a)

(b).

2. RF sputter a layer of Lithium Niobate for its piezoelectric properties. (b)

(c).

3. Spin coating PMMA A2 photoresist on top of the GaAs substrate with speed of 4500rpm for patterning which will provide a thickness of 100 nm. Bake the sample on hotplate with temperature of 180°C for 2 minutes. (c)

(d).

4. E-beam expose with the Raith Pioneer EBL for transferring the pattern with the mask described above onto the surface. (d)
5. Develop the photoresist in MIBK solution for 2 minutes to obtain the structure.

(e).

6. Metallization with E-beam evaporator to form the IDT electrode fingers by the thickness of 50nm. (e)

(f).

7. Lift-off the unwanted photoresist structure with acetone to get the IDT fingers on top of the piezoelectric material. (f)