The Study of the Temperature Dependence of Photoresponse in Superlattice Infrared Photodetectors

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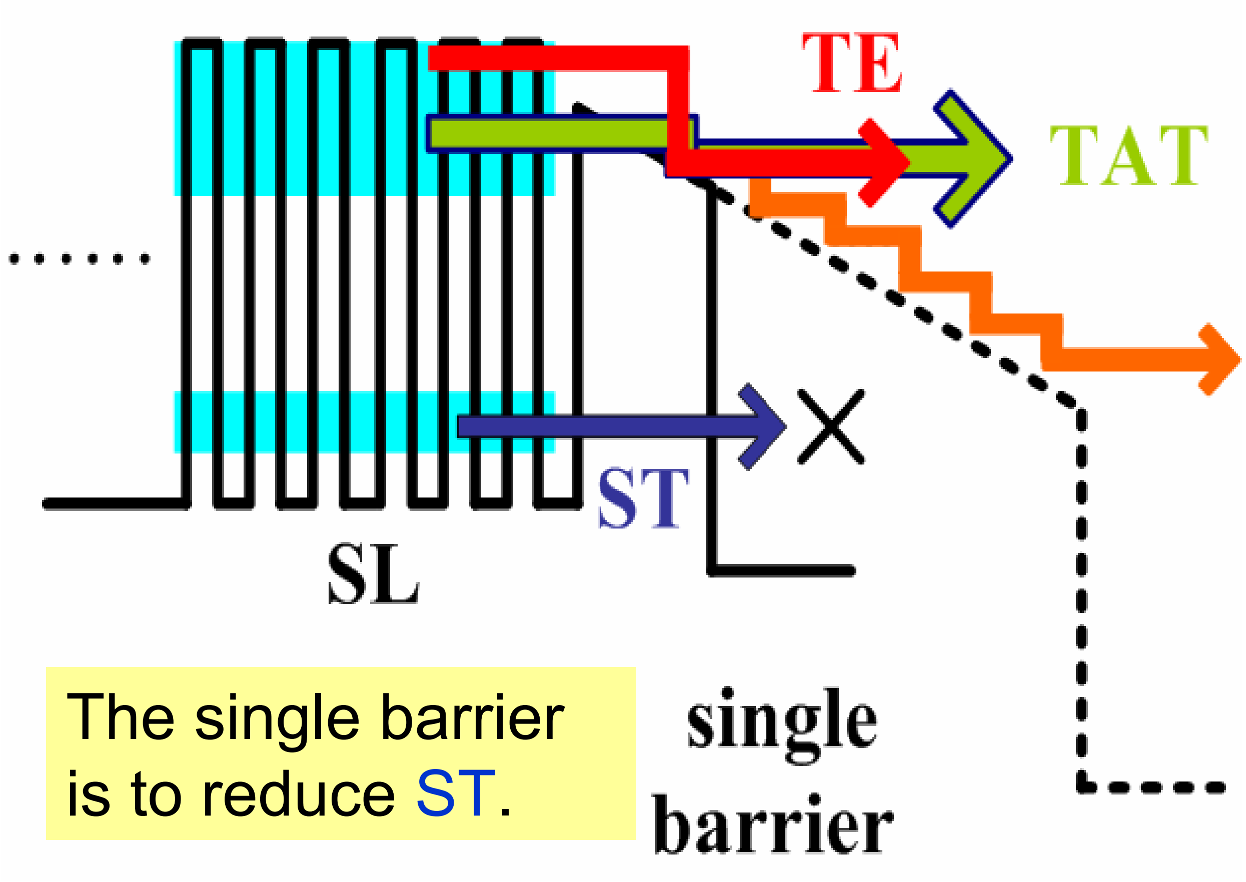
Introduction

TE and TAT depends on temperature and applied bias.

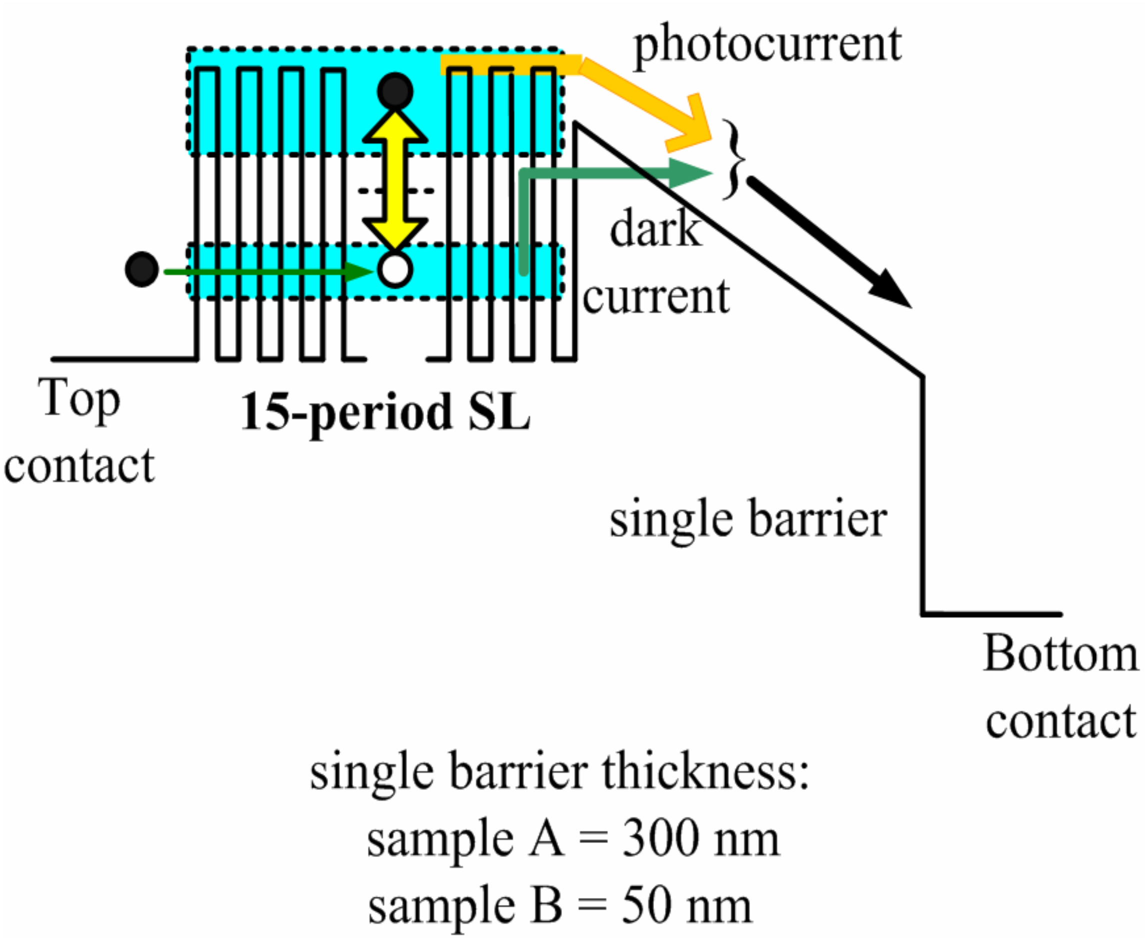


The electron transport through the barrier can be drift or ballistic depending on:

1. Barrier thickness
2. The applied bias

The single barrier is to reduce ST.

Sample Structure:
SL with a single barrier



Well / Barrier :

GaAs / $Al_{0.32}Ga_{0.68}As$

6.5 nm / 3.5 nm

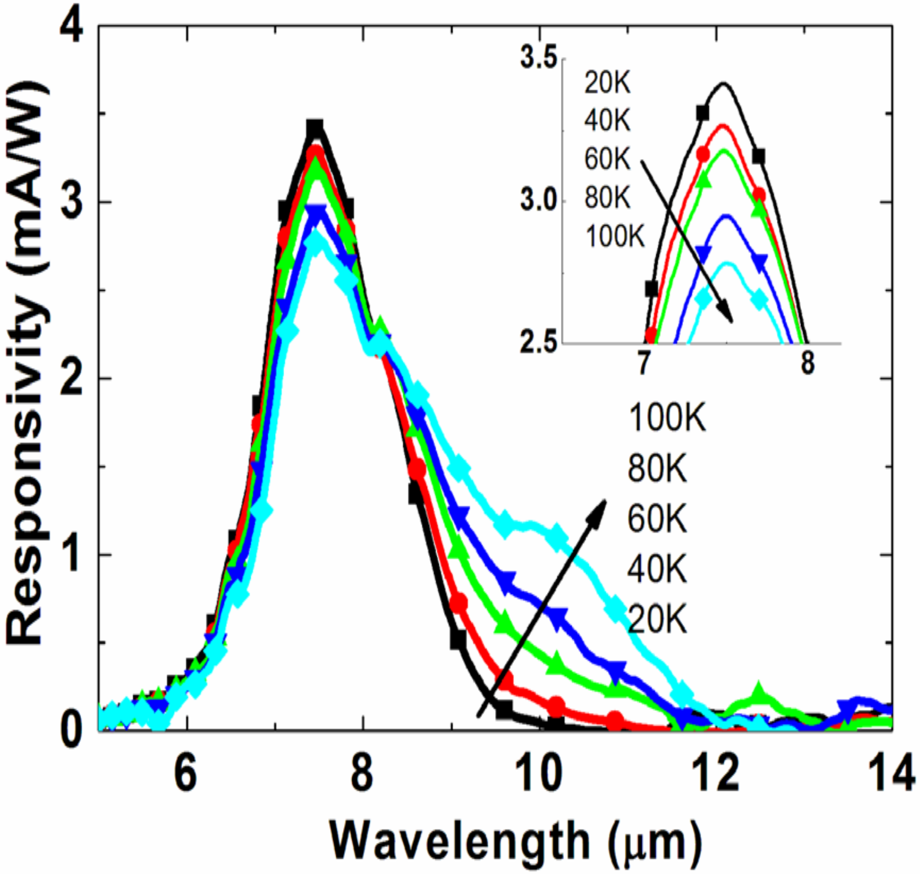
Doping Density :

5×10^{17} cm^{-3} in well

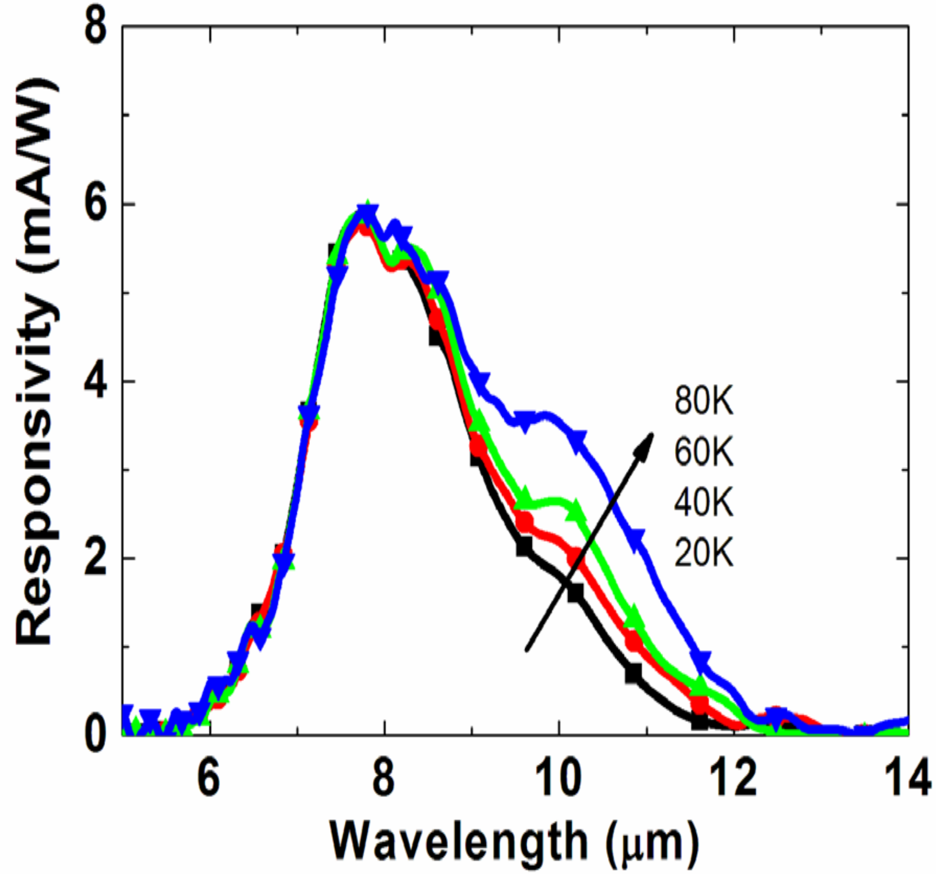
Single Barrier :

$Al_{0.25}Ga_{0.75}As$

The temperature dependence of response



Sample A at 0.5 V

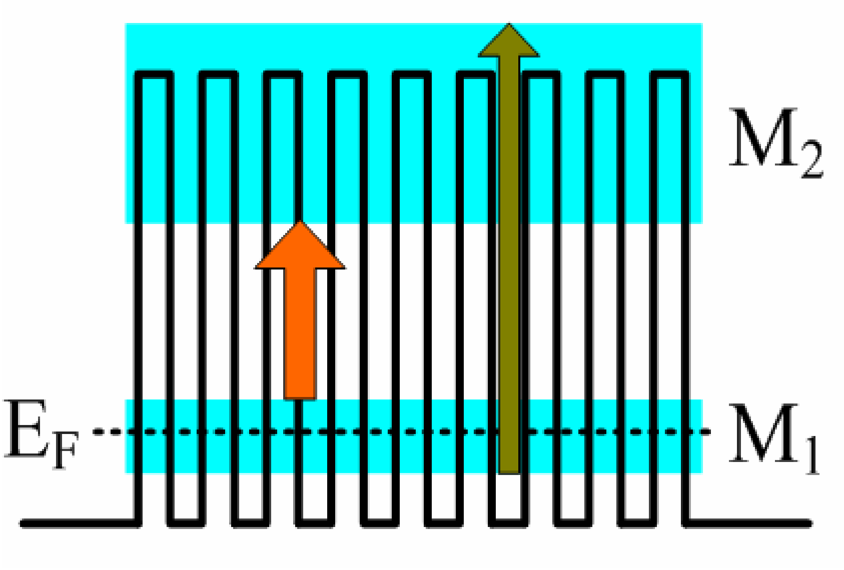


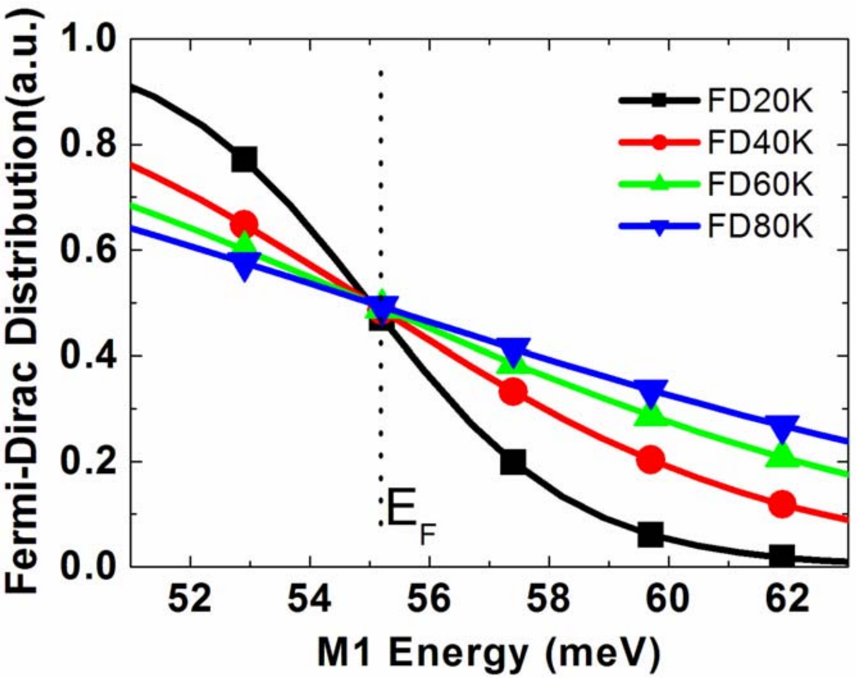
Sample B at 0.08 V

The thin-barrier sample has the larger responsivity under the same electric field.

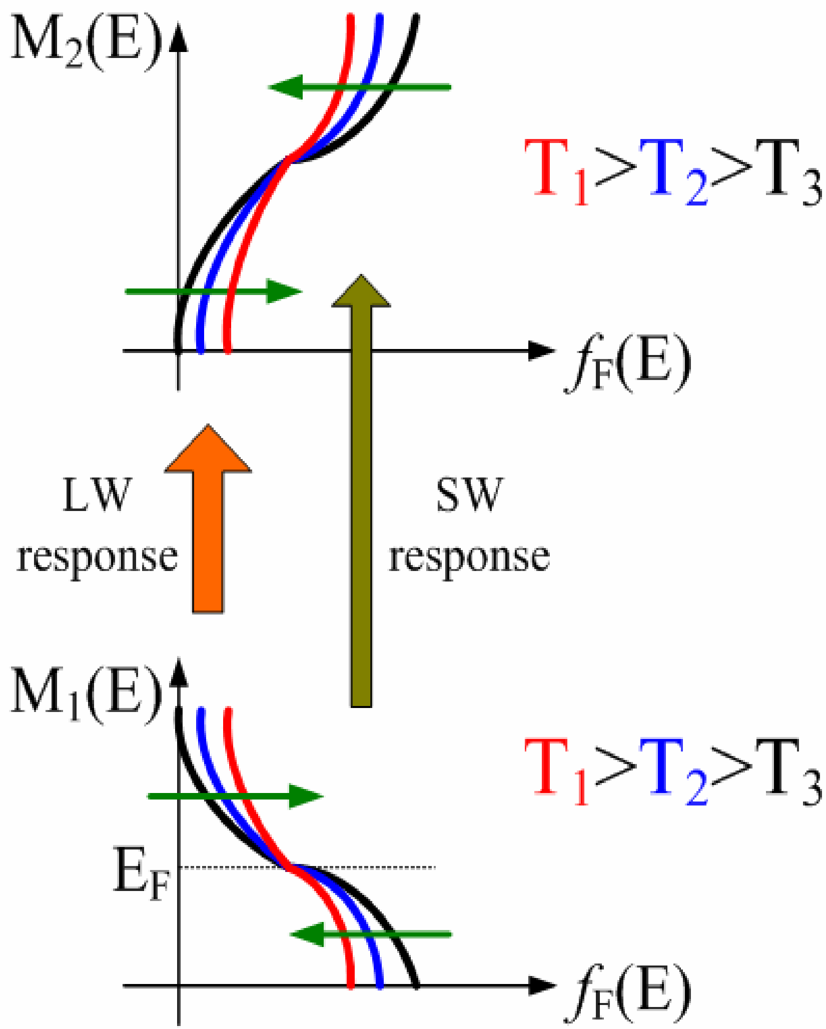
The effect of Fermi level

$$f_F(E) = \frac{1}{1 + \exp(\frac{E - E_F}{kT})}$$

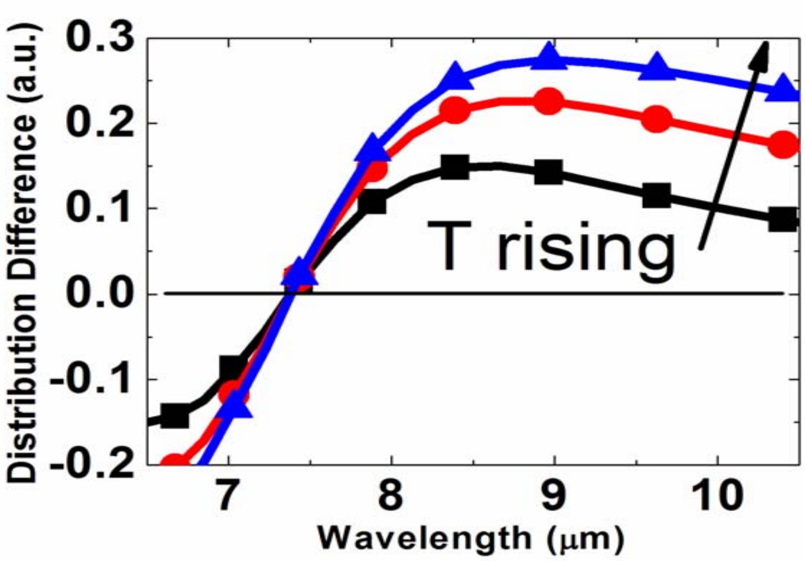




The calculated Fermi-Dirac Distribution

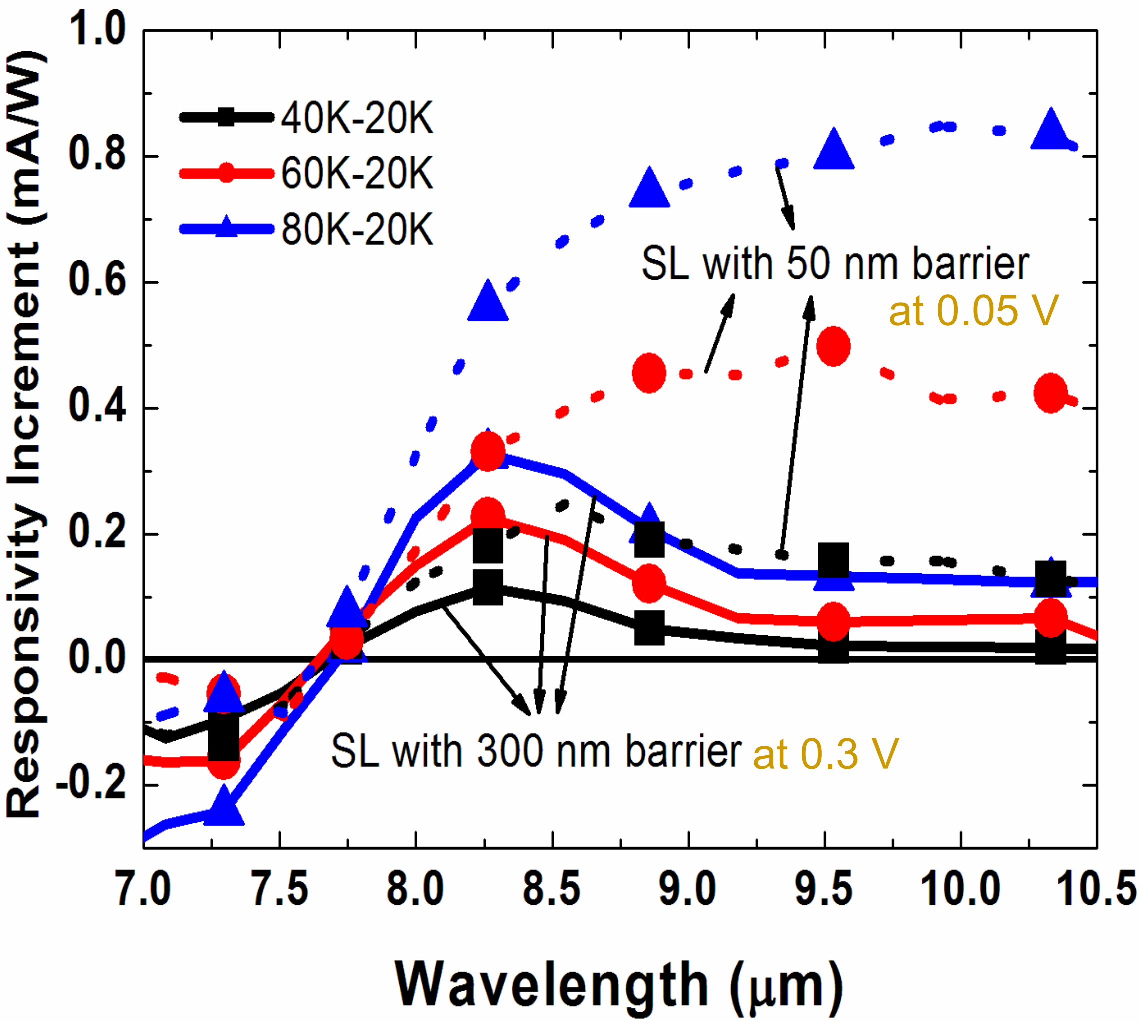


$$f_{F,\,\text{High T}}(E) - f_{F,\,20\,\text{K}}(E)$$

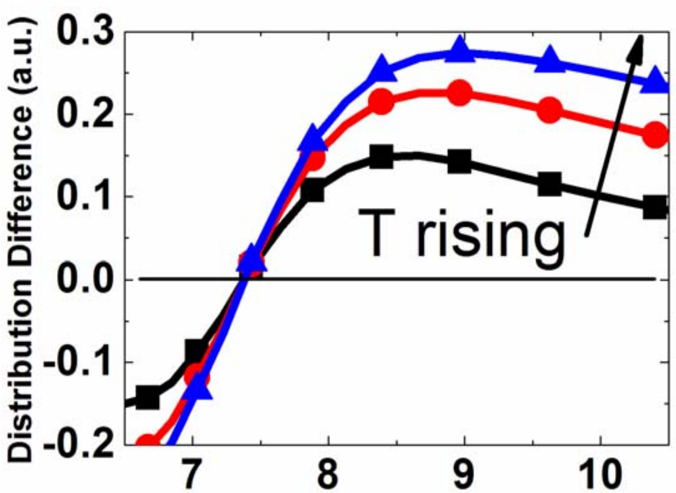


As temperature rising, the electron distribution of the state lower (higher) than the Fermi level decreases (increases), which leads to the decrement (increment) of the short (long) wavelength response.

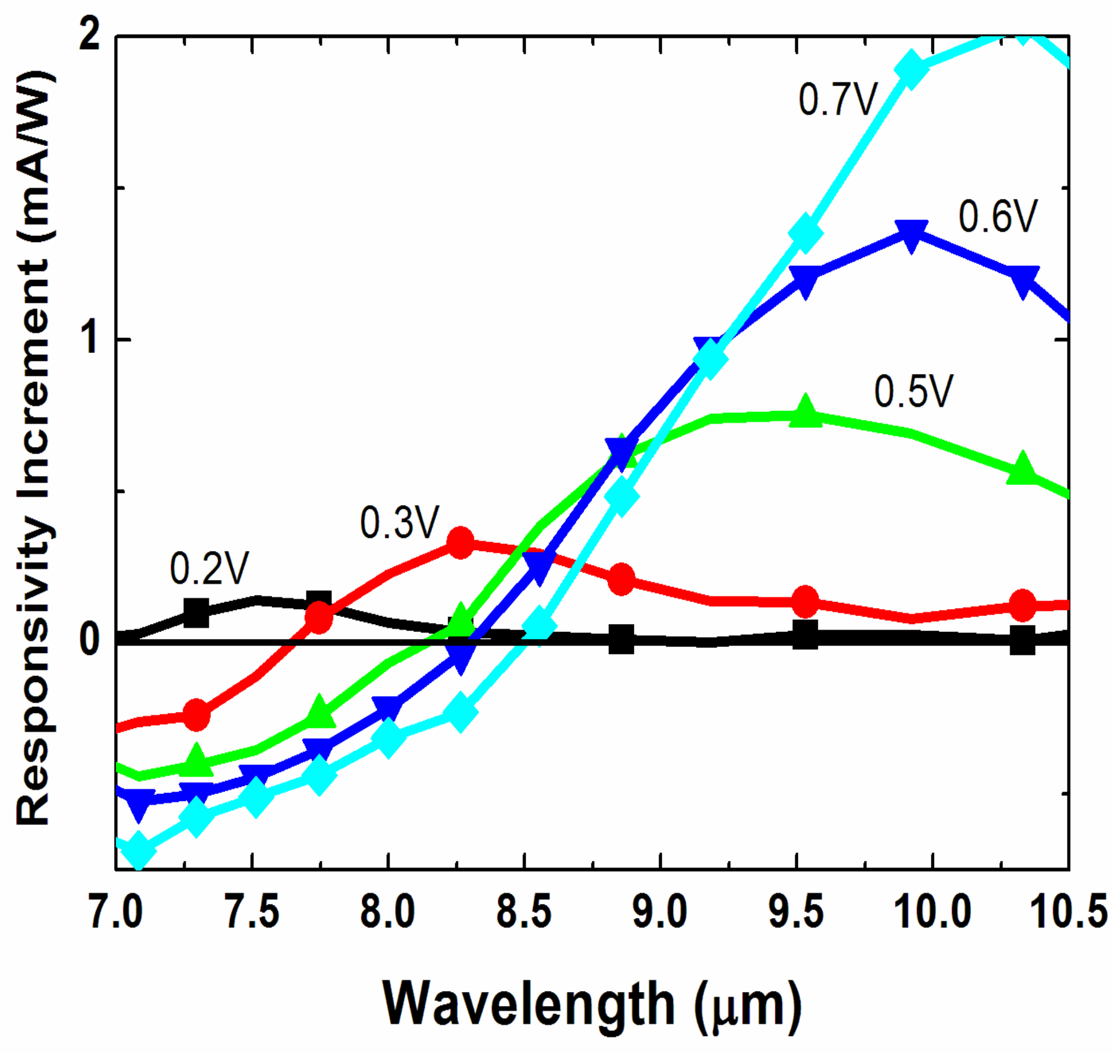
The effect of barrier thickness



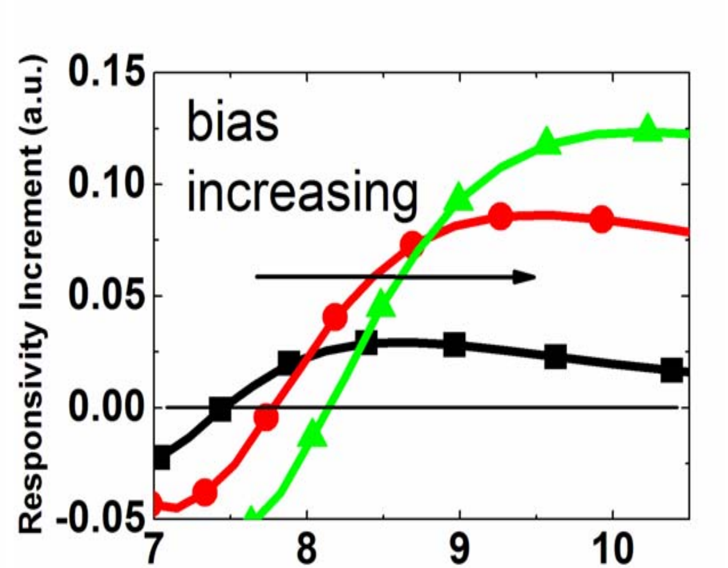
The thin-barrier sample has the larger increment than thick-barrier one, which means the ballistic transport in the thin barrier.



The effect of the applied bias

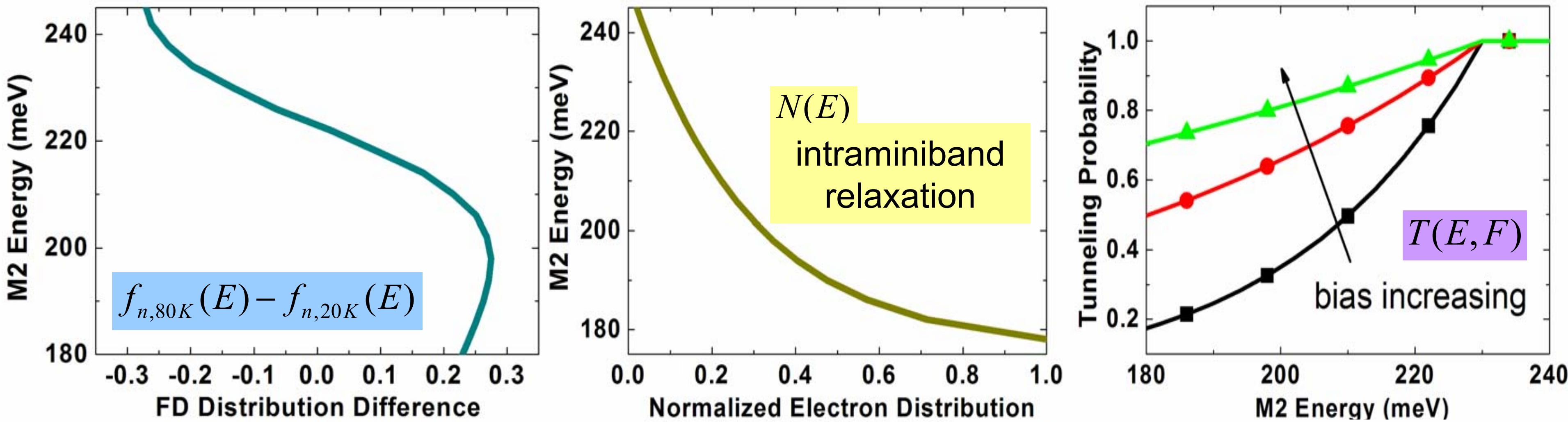


- The zero-crossing point shifts to the long-wavelength side as bias increasing.
- The increment grows as bias increasing.



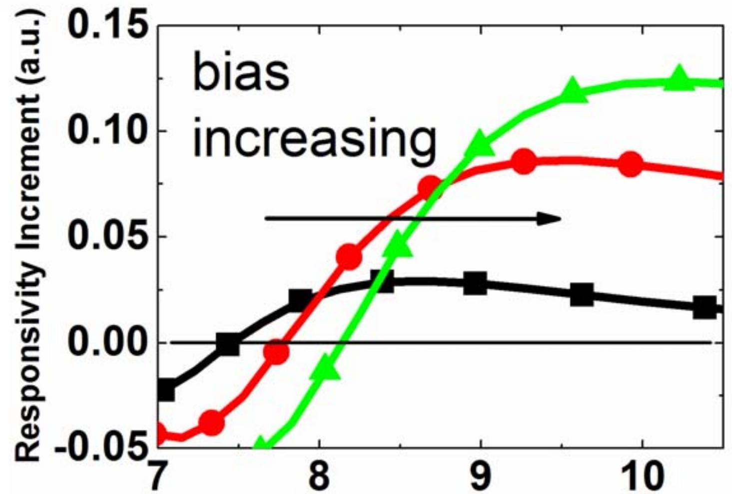
The effect of the applied bias

The fitting equation: $[f_{n,80K}(E) - f_{n,20K}(E)] \times N(E) \times T(E,F) - S_{bias}$



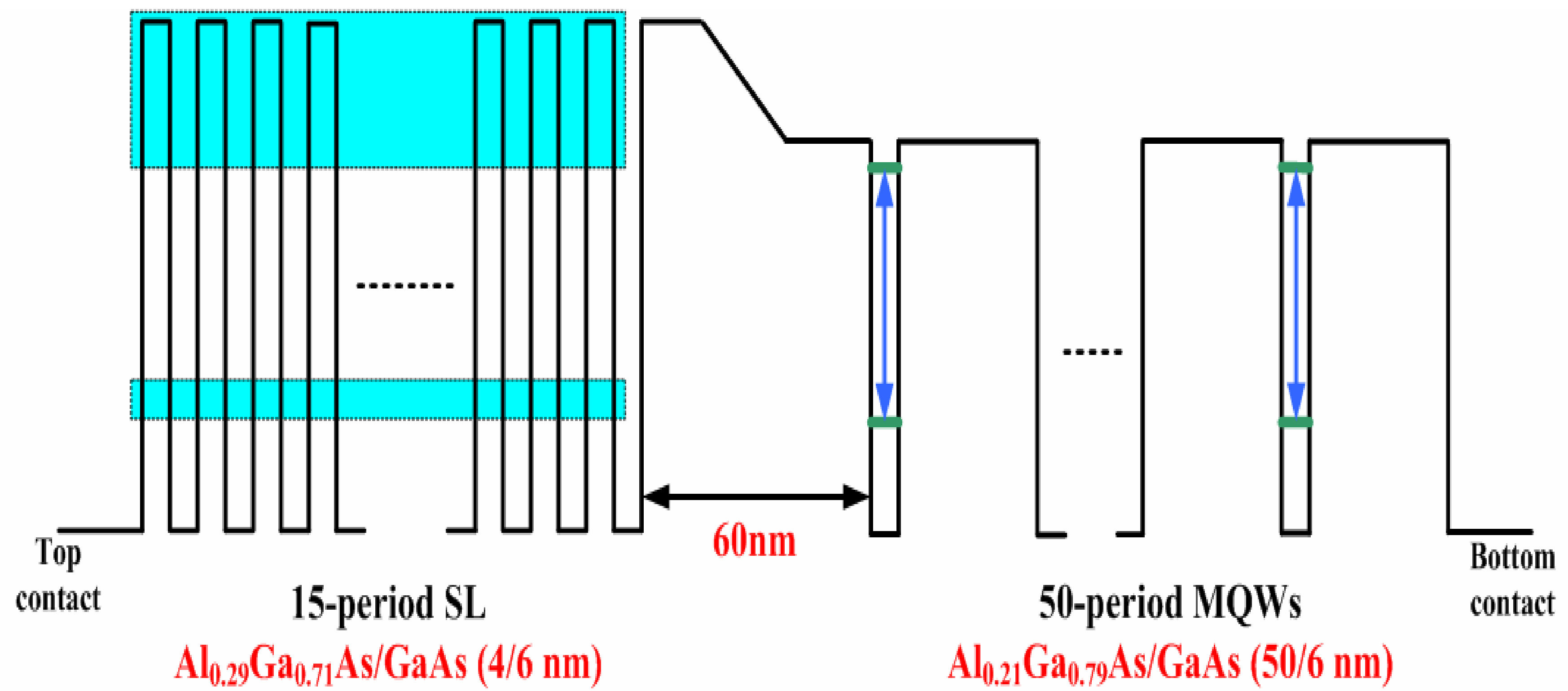
$N(E)$：electron distribution at the state in M_2, which is inversely proportional to number of the states below that state.

S_{bias}：the scattering in the barrier, which is proportional to the applied bias.



Sample structure: SL with MQWs

Doping Density : 4×10^{17} cm^{-3} in SL and MQWs



Design Principles

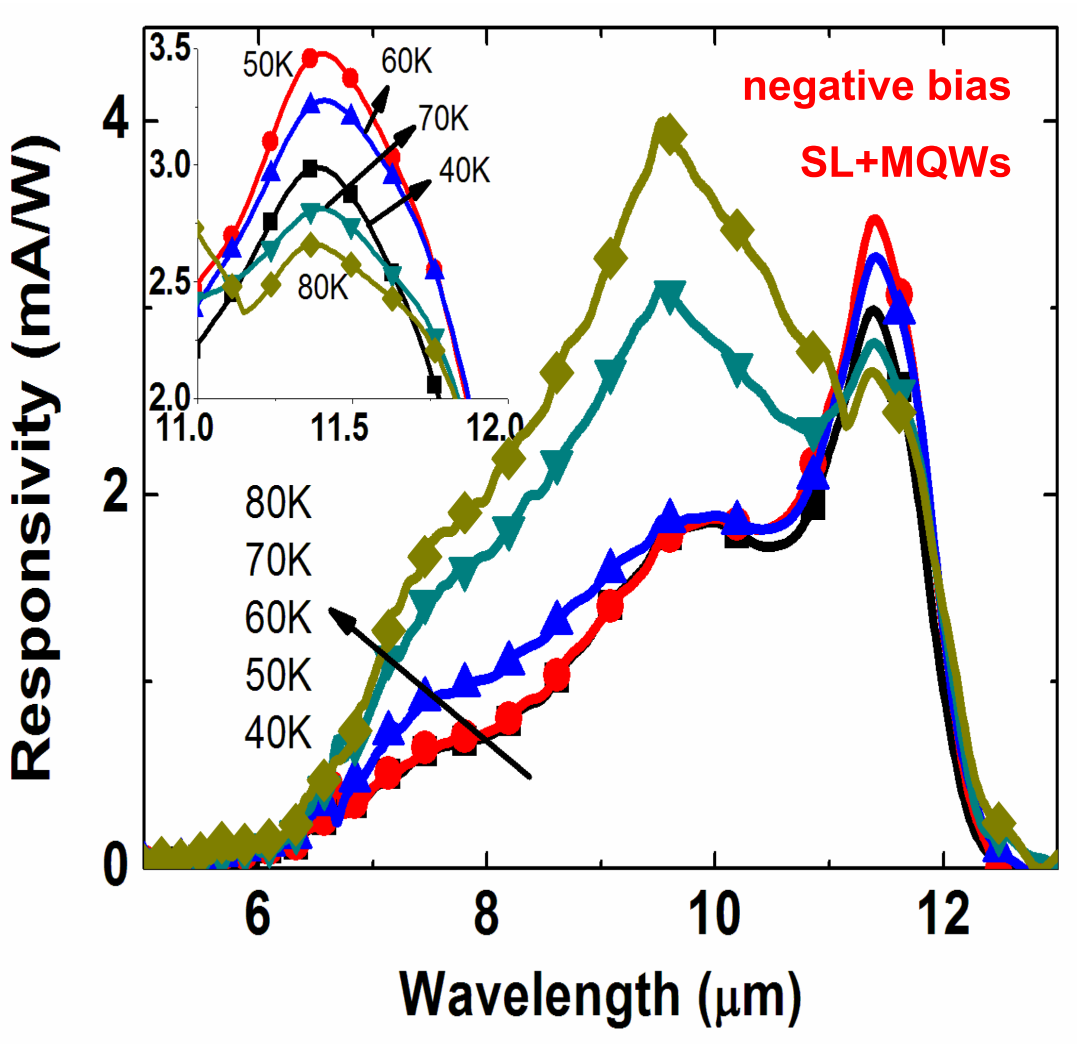
- The graded barrier thickness is 60 nm

  → *electrons can transport ballistically*
- The doping density is 4e17 cm^{-3}

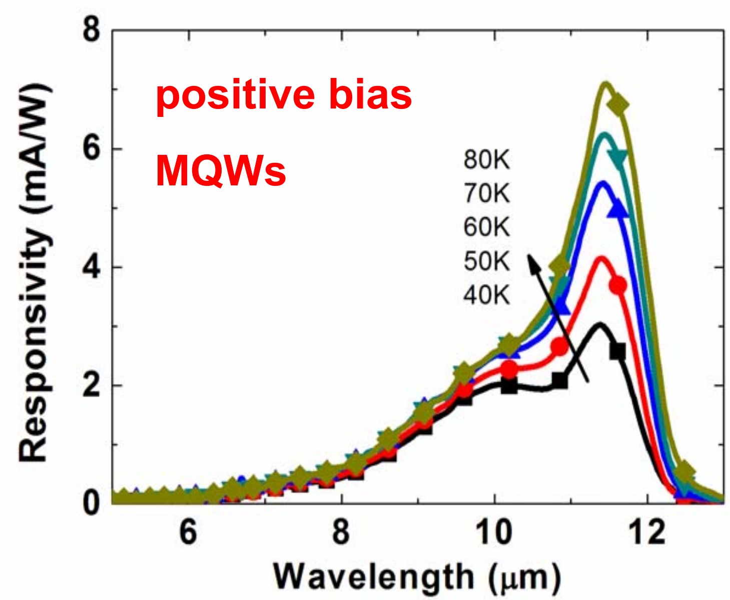
  → *the lower Fermi level causes the lower decrement of short wavelength response*
- The graded barrier height is raised

  → *all electrons have to go through the barrier by tunneling and depends on the applied bias*

Photoresponse at 0.5 V



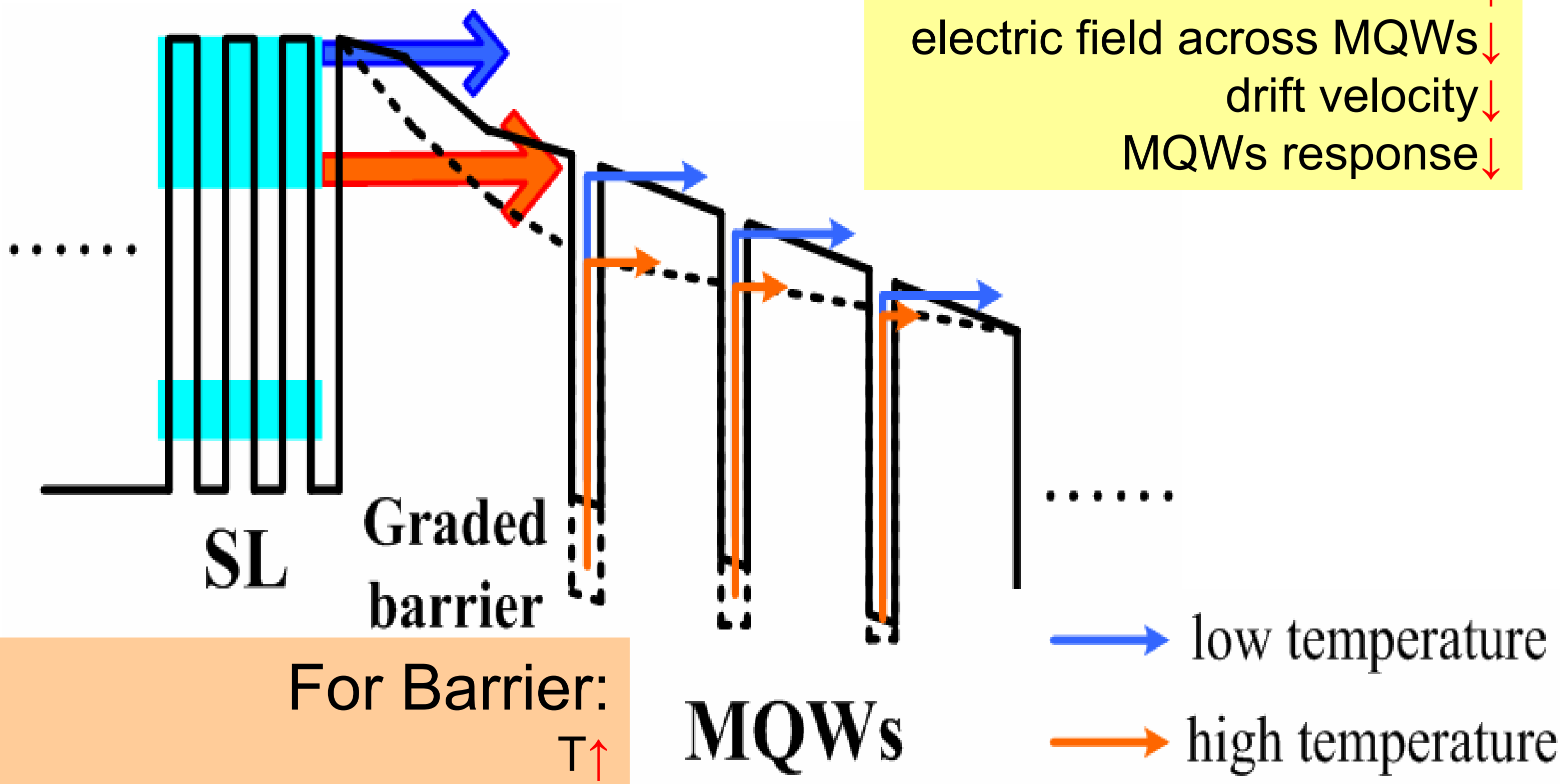
The temperature-enhanced response from MQWs is attributed to the thermally assisted tunneling.



Band diagram at same bias different T

For SL:
T↑
electric field across the graded barrier↑
tunneling probability↑

For MQWs:
T↑
electric field across MQWs↓
drift velocity↓
MQWs response↓



For Barrier:
T↑
electrons escape from MQWs↑
electric field across the graded barrier↑

Summary

- The factors such as the doping density, the barrier height and thickness, and the applied bias will affect the temperature dependence of photoresponse in SLIP.
- The fitting curves based on these factors are consistent with the experimental results.
- According to those factors, we design a structure of the combination of SL and MQWs to achieve the better temperature effect of photoresponse. It shows the temperature-enhanced photoresponse and achieves the broadband response under low bias and high temperature operation, which provides the flexibility for the high-temperature applications.