# New transmission-type photocathode structure based on strain-compensated superlattice

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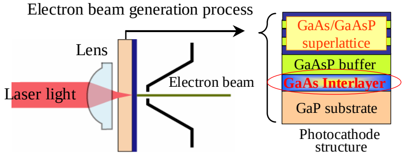
## Transmission-type super-high brightness and high polarization photocathode

### The current result

A transmission-type photocathode based on GaAs/GaAsP strained superlattice on GaP substrate

Electron beam generation process



Photocathode structure

Polarization 90%

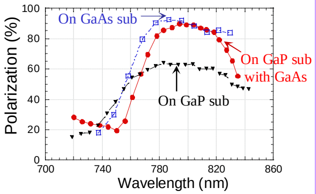
Brightness $1.3\pm0.5\times10^{7}$ A·cm$^{-2}$·sr$^{-1}$

| photocathode | Electron beam generation area | Brightness (A·cm$^{-2}$·sr$^{-1}$) |
|---|---|---|
| Transmission-type | **~1 μm$^2$** | **~$10^7$** |
| Reflection-type | ~10000 μm$^2$ | ~$10^3$ |

Using a short-focal-length lens, the spot size of laser light was greatly reduced.
A GaAs interlayer was introduced to control the strain in the GaAsP buffer layer.

### GaAs interlayer for high polarization

#### Polarization results

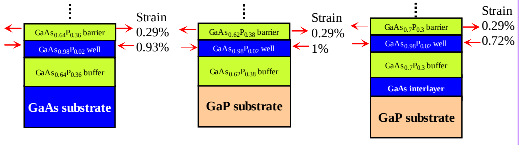


The polarization of GaAs/GaAsP superlattice depends on the substrate.

GaAs, GaP with GaAs interlayer: **~90%**
GaP substrate: **~60%**

#### Strain and valence band splitting in superlattices

Using XRD and PL measurement, the strain and valence band splitting in GaAs/GaAsP superlattices were calculated.

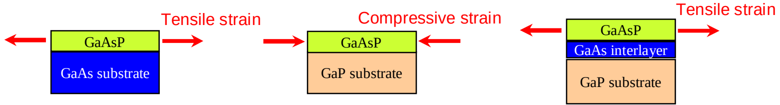


Valence band spliting 88 meV — Valence band splitting 93 meV — Valence band splitting 68 meV

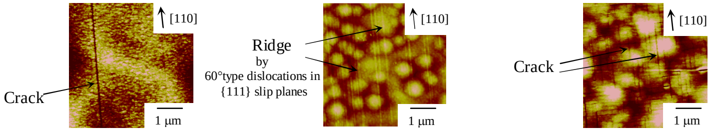
In each superlattice, the values of band splitting are enough to selectively excite electrons in the valence band.

Tensile strain and compressive strain in the GaAsP buffer layers are relieved by different mechanisms.

The lattice constant: GaAs > GaAsP > GaP



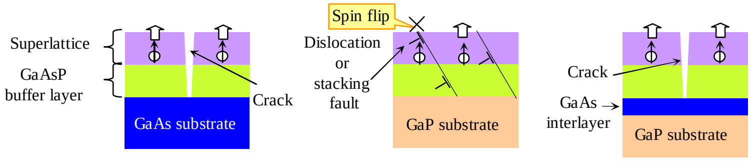
AFM image of the GaAsP layer on each substrate.



GaAsP on GaAs substrate and GaP substrate with GaAs interlayer were relieved by introduction of cracks.
On the other hand, GaAsP on GaP substrate was relieved by introduction of dislocations and stacking faults.

GaAs interlayer on GaP substrate induced the tensile strain in the GaAsP layer.

### The defects and polarization (The defects in the buffer layer can extend to the epitaxial layer grown on it)



The cracks have a little influence on spin polarized electrons.
On the other hand, the dislocations and stacking faults on the {111} planes affect spin polarized electrons.

♦ Now, TEM observation is being carried out to identify the defects in the GaAs/GaAsP superlattice layers.

## Strain-compensated superlattice for a high electron-beam current

### The design of the superlattice

**For a high electron-beam current, super-high brightness, and high polarization photocathode**

**For a high electron-beam current:** (1) To apply a high-power laser as excitation light. (2) To increase quantum efficiency: ･To use strain-compensated superlattice for high crystal quality; ･To improve the crystal quality of the buffer layer; ･To decrease electron affinity of the superlattice.

**For high brightness (transmission-type):** Transparent substrate to the excitation laser light.

**For high polarization**: The valence band splitting of 80 meV and over.

### Experiment

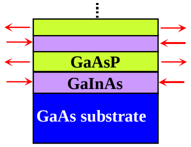
The photocathodes were fabricated by using a low-pressure organometallic vapor phase epitaxy (OMVPE) system. The crystalline quality and layer structure of the photocathodes were investigated by XRD measurement and PL measurement.

### GaInAs/GaAsP strain-compensated superlattice for applying a high-power laser

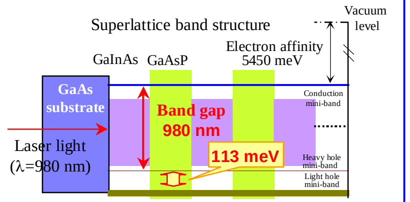
Presently, Ti:sapphire laser is used as excitation light. The power is only 0.1~0.2 W. On the other hand, the power of some semiconductor lasers is larger than 10 W. Moreover, the semiconductor laser is smaller in size and its cost is cheaper than that of Ti:sapphire laser.

The wavelength of semiconductor lasers are 900-1000 nm. In order to adjust to the wavelength, GaInAs/GaAsP strain-compensated superlattice was fabricated on the GaAs substrate.

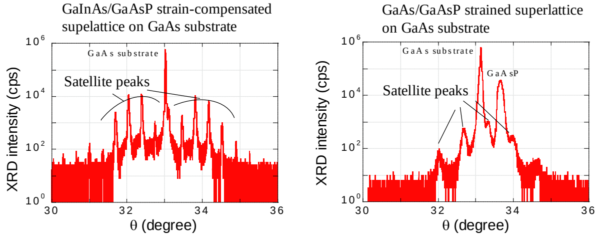
Superlattice structure



Superlattice band structure



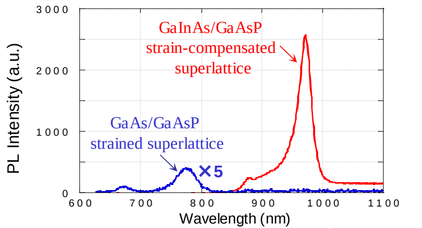
#### (004) XRD measurement



The satellite peaks from GaInAs/GaAsP are sharper and higher than those from GaAs/GaAsP.

Much periodical GaInAs/GaAsP strain-compensated superlattice layers were grown on GaAs substrate .

#### PL measurement



The peak intensity of GaInAs/GaAsP superlattice is 30 times higher than that of GaAs/GaAsP superlattice.

The defects in the GaInAs/GaAsP largely decreased.

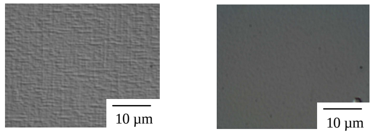
♦ Owing to a high power semiconductor laser and a good crystalline quality of GaInAs/GaAsP superlattice, a high electron-beam current is expected though the electron affinity of the GaInAs/GaAsP superlattice increases. Now, the measurement is being prepared.

### High quantum efficiency strain-compensated superlattice on GaP substrate

#### Buffer layer on GaP substrate

To realize the strain-compensated superlattice on GaP substrate, a lattice-mismatched buffer layer is necessary.

500 nm GaAs$_{0.64}$P$_{0.36}$ on GaP substrate — 500 nm GaAs on GaP substrate



The morphology of the GaAsP layer is rough, while that of the GaAs layer is very smooth. The lattice-mismatch effects the morphology of the epitaxial layer.

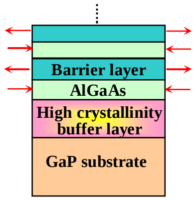
To obtain a high crystalline buffer layer on GaP substrate, by controlling the lattice-mismatch between the epitaxial layer and GaP substrate.

#### Strain-compensated superlattice

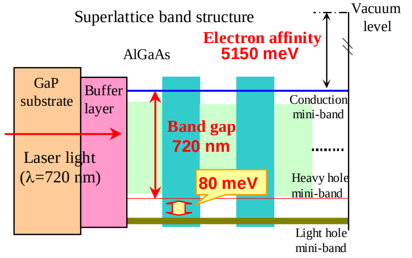
**For a high quantum efficiency**:

(1) For increase electron affinity, **AlGaAs** is used for well layer in the superlattice.
(2) AlGaAs well layer and barrier layer are strain-compensated on the buffer layer.

Superlattice structure



Superlattice band structure



The electron affinity (**5150 meV**) is by 80 meV smaller than that of the GaAs/GaAsP superlattice.

♦ High electron affinity strain-compensated superlattice with high crystallinity buffer layer on GaP substrate will be fabricated soon.

## Conclusion

･Developing a transmission-type photocathode on GaP substrate with a GaAs inter layer, super-high brightness and high polarization electron beam was achieved.

･ For a high electron-beam current, we proposed two strain-compensated superlattice structures; (1) GaInAs/GaAsP superlattice on GaAs substrate was fabricated for using a high power semiconductor laser, and (2) a strain-compensated superlattice with AlGaAs on GaP substrate was designed for a high quantum efficiency.