

## Infrared Detector Arrays for Thermal Imaging Tutorial "Infrared Detectors"

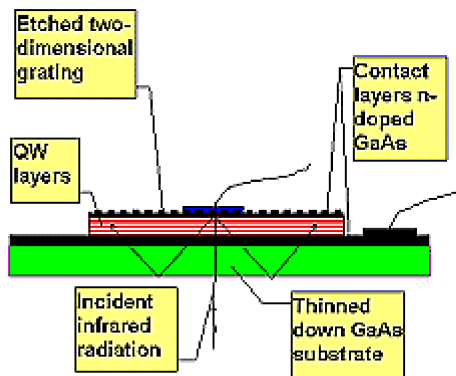
### A. Quantum Well Infrared Photodetector (QWIP) Arrays

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#### *Introduction and Basic Principles*

By appropriate design of [quantum wells](#) in certain semiconductor materials, electronic levels can be tailored to absorb radiation in the long wavelength infrared region (wavelength 3-20  $\mu\text{m}$ ). An excellent material combination in this respect is the aluminum gallium arsenide/gallium arsenide (AlGaAs/GaAs) material system, with gallium arsenide (GaAs) being the substrate material.

The advantage of using GaAs is its mature processing technology compared to the conventional materials now used for this application, primarily mercury cadmium telluride (HgCdTe). Good quality wafers of 4" size are commercially available. Especially for large two-dimensional arrays, where uniformity is extremely important, GaAs based technology is very competitive



*Fig. 3. Scheme of quantum well infrared detectors for 8-10  $\mu\text{m}$  wavelength, with a crossed grating coupler. The substrate material is thinned down.*

Fig. 4 is a close up of a detector array showing the detector mesas with the two-dimensional etched gratings on top. In order to optimize the reflection properties of the gratings they are covered with gold. The central part of the surface acts as an electrical contact, and here gold germanium alloy is used instead. Gold germanium is the standard contact metal for making contacts to n-type gallium arsenide.

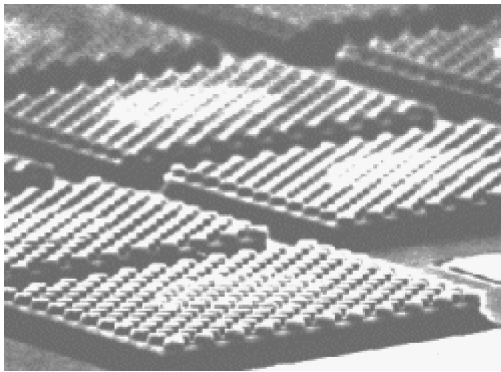


Fig.4. A close up of a QWIP array, showing the mesa structure of the detector elements with the 2-dimensional gratings on top.

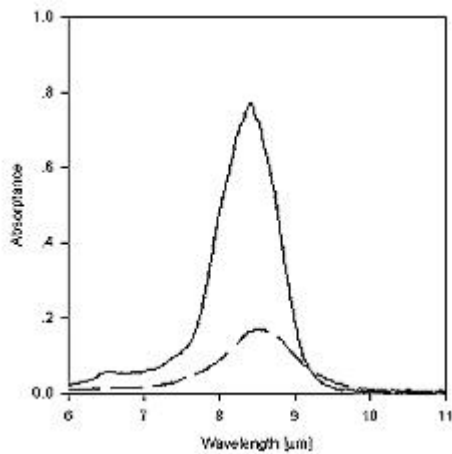


Fig. 5. Spectral absorptance vs.wavelength of a QWIP pixel (full curve), and of a corresponding polished edge detector (dashed). Both curves refer to unpolarized radiation.

### **Dark Current and BLIP Temperature**

The drawback of QWIP detectors is their comparatively large dark current. For a detector responding in the range 8-9.5  $\mu\text{m}$ , cooling to temperatures down to 70-73 K is necessary in order to reduce dark currents to a sufficiently low level. The temperature of background limitation (BLIP) is about 72K assuming the following optical parameters when the detector is part of an imaging camera system:  $\# = 1$  and transmission of the optical system = 100%. It is here assumed that the BLIP temperature is defined as the temperature where the photocurrent is ten times as large as the dark current. Operating temperatures around 70 K are easily achievable by e.g. miniature Stirling coolers, now in common use for small hand held camera systems.

The most important origin of dark current in QWIPs is [longitudinal optical phonon](#) excitation of carriers, and is very fundamental and therefore difficult to get rid of, except by decreasing the detector temperature. The reason for this is that coupling between optical phonons and charge carriers is very strong in [III-V materials](#) such as GaAs. There is

however one advantage of this fact: the dark current distribution between pixels in a detector array becomes very uniform and is thus comparatively easy to compensate for.

Fig. 6 displays the BLIP behaviour of a QWIP. The curve indicated with the photocurrent to dark current ratio of ten conforms with the same definition of BLIP temperature as used above. It is evident from the figure that the cooling requirements become severer the larger the cut-off wavelength is. This is a general fact for all types of infrared photon detectors.

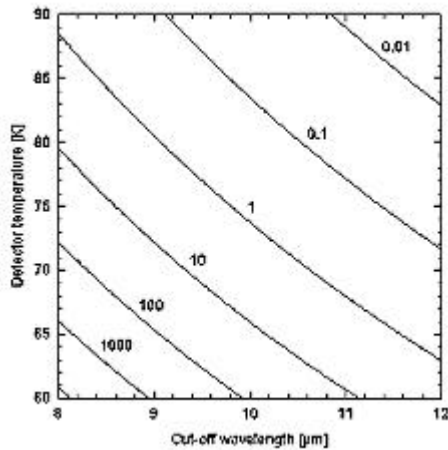


Fig. 6. Contour plot displaying (calculated) levels of constant ratio: photocurrent / dark current vs. cut-off wavelength and detector operating temperature. Assumptions: detector with two-dimensional grating and thinned down substrate, optics  $f\#=1$  and transmission 100 %. Background temperature = 300K.

## Detector Arrays

### Device Fabrication

320x240pixels QWIP arrays have been fabricated at ACREO. Such detector arrays consist of a QWIP chip [indium bump flip-chip](#) bonded to a silicon CMOS readout integrated circuit (ROIC). The fabrication process consists of the following steps:

- Fabrication of QWIP chip (based on GaAs)
  - Epitaxial growth of QWIP structure
  - Processing of QWIP array
- Fabrication of ROIC (based on silicon CMOS)
- Processing of indium bumps
- Hybridization - Flip-chip bonding
- Mounting and wire bonding

The first step is to grow the QWIP structure by [MOVPE](#) starting with a semi-insulating GaAs wafer. A typical QWIP structure consists of 50 quantum wells, each of width 5.0 nm surrounded by AlGaAs layers ( $x = 0.28$ ) of width 35 nm. On either side of the QW structure is a contact layer consisting of highly n-doped GaAs.

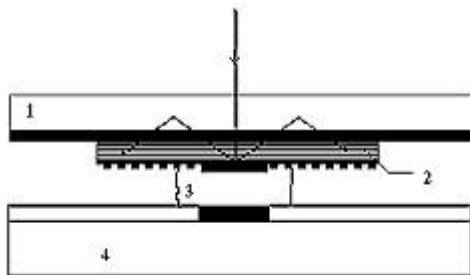
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The next step is to lithographically define and etch gratings into the uppermost part of the mesa. The gratings have rectangular profile with the dimensions: grating constant = 2.75  $\mu\text{m}$ , cavity width = 1.8  $\mu\text{m}$  and depth = 0.9  $\mu\text{m}$ . Then detector mesas are fabricated by etching down to the lower contact layer. Finally metal contacts are made and a layer of gold deposited over the grating. The latter acts as a reflector for the radiation.

The [ROIC](#) is based on direct injection, silicon CMOS, and has one charge storage capacitor per pixel. The output signal has a serial analogue format. Amplification, A/D conversion and pixel correction is done externally to the chip.

Indium bumps are then processed onto the chips, after which the QWIP and ROIC chips are aligned and bonded in a [flip-chip bonder](#). The GaAs substrate is finally thinned down by a combination of lapping and chemical etching.

Fig. 7 shows a cross-section through a detector pixel. Pixels are of square shape of side length about 30  $\mu\text{m}$ . The pitch between pixels is 38  $\mu\text{m}$ .



*Fig. 7. Scheme of detector pixel in cross-section 1 = dielectric reflector, 2 = QWIP structure, 3 = indium bump, 4 = readout circuit. The arrows show the incident radiation, together with the multiple passes of the radiation diffracted by the grating.*

The hybridized QWIP array mounted onto a ceramic substrate and wire bonded is shown in Fig. 8. The total size of the chip is 11x14 mm.

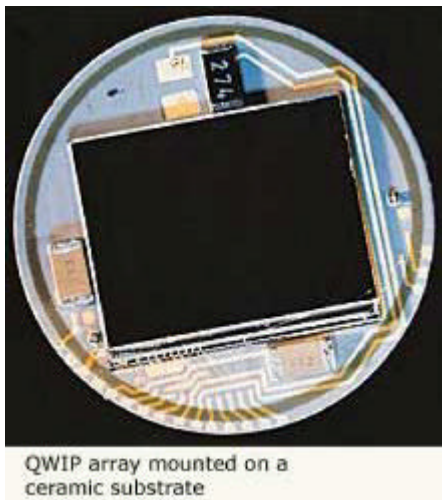


Fig.8. Photograph of a 320x240 pixels hybridized detector array mounted onto a carrier substrate. The total size of the chip is 11x14 mm. The pitch between pixels is 38  $\mu\text{m}$ .

### Array Performance

The 320x240 pixels QWIP array fabricated at ACREO has the following characteristics

- The detector has maximum response at about 8.5 - 8.8  $\mu\text{m}$ , and spectral characteristics as shown in Fig. 5.
- The operation temperature is 70-73 K, achievable by a miniature Stirling cooler
- QWIP technology offers excellent uniformity. 2 -4 % across an array. (See histogram in Fig. 9)
- Noise equivalent temperature difference (NETD) is 30-40 mK
- Images are obtained by a two-point calibration procedure

An image of a person obtained by such a QWIP array is shown in Fig.10. Cold areas of the image are dark and warmer areas brighter.

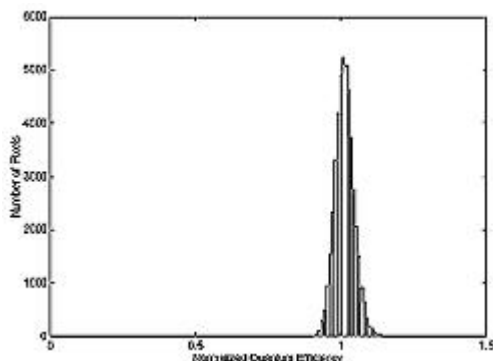


Fig. 9. Histogram of quantum efficiency normalized to unity mean value. The standard deviation is 3.3 % of the mean value across an array.



Development of detector arrays of higher resolution is underway. The main application insight is thermal imaging, for both civilian and military purposes.

### **Present QWIP projects at ACREO**

ACREO is presently involved in a R&D project on high resolution LWIR detector arrays, MWIR and two-color arrays (i.e. MWIR + LWIR). Array sizes will be about 640x480 pixels for the LWIR arrays. The project is supported by FSI (FLIR Systems Inc.), CelsiusTech AB, Saab Dynamics AB, FMV (Defence Materiel Administration) and NUTEK (Swedish National Board for Industrial and Technical Development).

### **Important Publications on QWIPs**

1. J. Y. Andersson and L. Lundqvist, "Near-unity quantum efficiency of AlGaAs/GaAs quantum well infrared detectors using a waveguide with a doubly periodic grating coupler", *Appl. Phys. Lett.* 59 (1991) p. 857-859
2. J. Y. Andersson and L. Lundqvist, "Grating coupled quantum well infrared detectors: Theory and performance", *J. Appl. Phys.* 71 (1992) p. 3600-3610.
3. L. Lundqvist, J. Y. Andersson, Z. F. Paska, J. Borglind, and D. Haga, "Efficiency of grating coupled AlGaAs/GaAs quantum well infrared detectors", *Appl. Phys. Lett.*, 63 (1993) p. 3361-3363.
4. J. Y. Andersson and L. Lundqvist, "Grating coupled quantum well detectors", in *Long Wavelength Infrared Detectors*, Vol. 1, Ed. M. Razeghi, part of the series *Optoelectronic Properties of Semiconductors and Superlattices*, p. 207-270, Series Editor M. O. Manasreh, Gordon and Breach Science Publishers, ISBN 2-88449-208-9.
5. J. Y. Andersson, "Dark current mechanisms and conditions of background radiation limitation of n-doped AlGaAs/GaAs quantum-well infrared detectors", *J. Appl. Phys.* 78, pp. 6298-6304, 1993.
6. J. Y. Andersson, J. Alverbro, J. Borglind, P. Helander, H. Martijn, and M. Östlund, "320x240 pixels quantum well infrared photodetector (QWIP) array for thermal imaging: fabrication and evaluation", *Proceeding of the SPIE, Infrared Technology and Applications XXIII*, Vol. 3061, pp. 740-748, 1997.