Infrared Physics & Technology 54 (2011) 194–198

Contents lists available at ScienceDirect

Infrared Physics & Technology

journal homepage: www.elsevier.com/locate/infrared

Status of quantum well infrared photodetector technology at QmagiQ today

Mani Sundaram *, Axel Reisinger, Richard Dennis, Kelly Patnaude, Douglas Burrows, Jason Bundas, Kim Beech, Ross Faska

QmagiQ, 22 Cotton Road, Suite 180, Nashua, NH 03063, USA

ARTICLE INFO

Article history:
Available online 25 December 2010

Keywords:
QWIP
Quantum well infrared photodetector
Longwave infrared
Focal plane array

ABSTRACT

The current state of focal plane arrays (FPAs) made from quantum well infrared photodetectors (QWIPs) is presented. In the last decade, QWIP technology has successfully transitioned at several companies from research and development to manufacturing and, today, represents a commercial success in cooled high-performance longwave infrared imaging. Technical performance metrics such as quantum efficiency, temporal and spatial noise, maximum frame rate and operating temperature, array uniformity and pixel operability, and manufacturing reproducibility are presented.

1. Introduction

QWIP technology has been extensively researched in the last 25 years [1,2]. The technology held out early promise of high yield and low cost due to the maturity of growth and processing of the GaAs/AlGaAs material system. That promise has been realized.

One criticism often leveled at QWIP is its low internal (~20%) and external (~7%) quantum efficiencies. In practical terms, this restricts the technology to imaging applications at F/5 or less at frame rates of 500 Hz or less, higher F numbers and frame rates requiring higher quantum efficiency. In these scenarios, however, QWIP FPAs perform quite superbly in terms of low temporal noise, high array uniformity and pixel operability, and excellent image stability.

A second criticism is the lower operating temperature required by QWIP to cut dark current and improve noise. A standard longwave QWIP with 8–9 μm spectral response needs to run at ~68–72 K, compared to ~80 K for a mercury cadmium telluride (MCT) photodiode FPA with 10 μm cutoff. The extra cooling this entails does not impose a significant burden on the QWIP.

Finally, QWIP has successfully ridden the coat-tails of the mobile phone industry which has driven huge improvements in GaAs-based growth and processing. With significantly lower market share than midwave infrared InSb FPAs, QWIP has been able to offer comparable quality and pricing to InSb, key factors in its commercial success.

2. QWIP FPA manufacturing

QWIPs are realized as doped quantum wells of GaAs sandwiched between barriers of AlGaAs, with the 40- or 50-period multi-quantum-well stack bracketed by top and bottom ohmic contact layers of n-doped GaAs. The GaAs well width and AlGaAs barrier composition (viz. Al%) determine the QWIP's spectral response which has a roughly Lorentzian shape with full width half maximum (FWHM)/Peak = $\Delta\lambda/\lambda \sim 10\%$. Most QWIPs manufactured and sold today have a spectral response of 8–9 μm or 10–11 μm, with a peak in the middle of the band.

Our material is grown on 4 in. or 6 in. GaAs substrates in multiwafer production molecular beam epitaxy (MBE) reactors, which offer excellent material uniformity (between wafers in a run), reproducibility (from run-to-run years apart), and ultra-low surface defect density – all these qualities being monitored by characterization techniques such as X-ray and defect mapping.

Detector arrays of the required format are printed in a wafer-level process using automated steppers for photolithography and inductively-coupled plasma (ICP) dry etching for grating and pixel definitions. Following ohmic metallization, the wafers are bumped and sawn into individual die which are then graded.

Subsequent steps involve batched die-level operations – each grade-A detector die is hybridized (i.e. flip-chip bump-bonded) to a matching bumped read out integrated circuit (ROIC) die, post-processed to have the entire detector GaAs substrate removed (leaving a ~5 μm thick QWIP membrane glued to the ROIC), packaged, and tested. Sample FPAs from each lot are measured for spectral response; every FPA undergoes radiometric measurements which generates a test report containing histograms of responsivity, temporal noise, spatial noise, etc., and a composite bad pixel

* Corresponding author. Tel.: +1 603 821 3092x200; fax: +1 603 821 3094.
E-mail address: msundaram@qmagiq.com (M. Sundaram).

1350-4495/$ - see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.infrared.2010.12.012

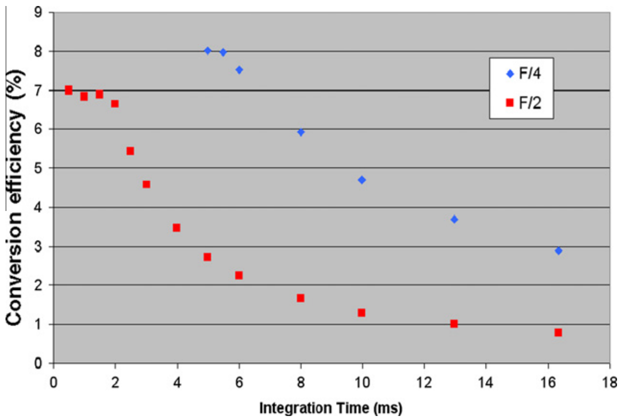

Fig. 1. Conversion efficiency versus integration time for QWIP FPA at two different F/#s. Global bias is changed simultaneously with the integration time. A maximum of 7%–8% is reached.

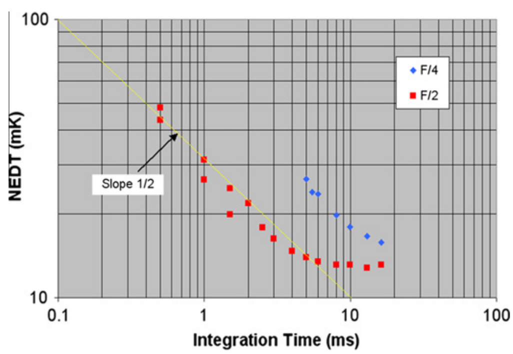

Fig. 2. Temporal NEDT of QWIP FPA at 68 K, corresponding to the operating points in Fig. 1. Integration times of 1 ms (F/2) and 5 ms (F/4) can be reached while preserving temporal NEDT <25 m K, corresponding to frame rates of 1000 Hz and 200 Hz, respectively.

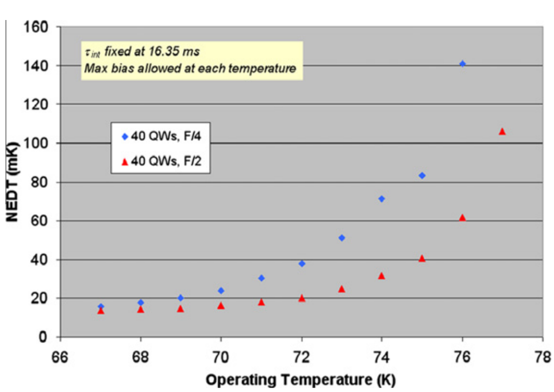

Fig. 3. Temporal NEDT versus operating temperature for QWIP FPA at a frame rate of 60 Hz. The FPA can be operated at 74 K (F/2) and 71 K (F/4), and maintain temporal NEDT <30 m K.

map. Automated comparison with customer specifications is used to assign a performance grade to each FPA. The ones that pass are delivered, together with detailed test reports.

3. FPA performance results and discussions

Here we detail the measured performance of a typical QWIP FPA with format = 320 × 256, pixel pitch = 30 μm, ROIC = ISC9705 (from FLIR Systems CVS), and spectral response = 8–9 μm. We have

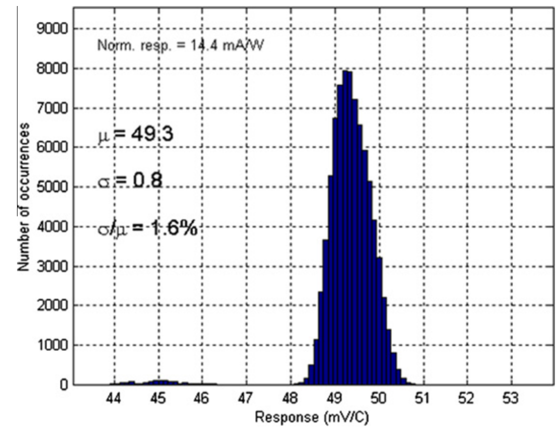

Fig. 4. Histogram of optical response of 320 × 256 QWIP FPA (F/4, 68 K) with aperture-shading effect removed and before two-point NUC, showing excellent array uniformity.

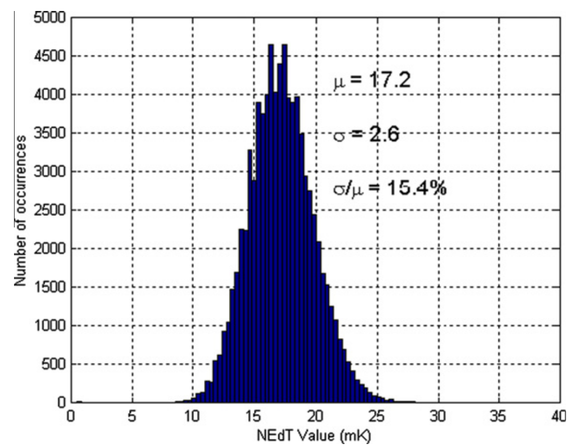

Fig. 5. Histogram of temporal NEDT of 320 × 256 QWIP FPA (F/4, 68 K) after two-point NUC at 20 °C and 40 °C, showing very low noise.

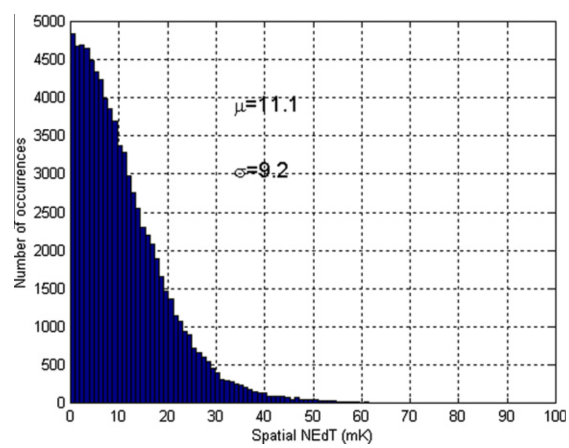

Fig. 6. Histogram of residual spatial NEDT at 30 °C scene temperature after two-point NUC at 20 °C and 40 °C, showing negligible residual non-uniformity.

delivered over a thousand such FPAs in the last 6 years, almost all of which are in field use. We stress that the performance of 640 × 512 format arrays (of which he have delivered a significant number also) is very similar. 1 K × 1 K FPAs have yet to achieve traction in the market; hence, "typical" performance data is not yet available.