A multiwavelength focal plane array infrared detector is included on a common substrate having formed on its top face a plurality of InGaAs absorption layers, between each pair of which a plurality of InAs buffer layers are formed having substantially increasing lattice parameters, respectively, relative to the substrate, for preventing lattice mismatch dislocations from propagating through successive ones of the absorption layers of decreasing bandgap relative to the substrate, whereby a plurality of detectors for detecting different wavelengths of light for a given pixel are provided by removing material above given areas of successive ones of the absorption layers, which areas are doped to form a pn junction with the surrounding unexposed portions of associated absorption layers, respectively, with metal contacts being formed on a portion of each of the exposed areas, and on the bottom of the substrate for facilitating electrical connections thereto.

9 Claims, 8 Drawing Sheets
OTHER PUBLICATIONS


Fig. 2

- In$_{0.53}$Ga$_{0.47}$As
- In$_{0.53}$Ga$_{0.47}$As fit
- In$_{0.7}$Ga$_{0.3}$As
- In$_{0.7}$Ga$_{0.3}$As fit
- In$_{0.85}$Ga$_{0.15}$As
- In$_{0.85}$Ga$_{0.15}$As fit

Volts

Current (Amps)
1
MULTIWAVELENGTH INFRARED FOCAL PLANE ARRAY DETECTOR

GOVERNMENT RIGHTS

This invention was made with Government support under Contract No. N00014-93-1-0223P00001, awarded by the Office of Naval Research, Department of Defense, and NASA Jet Propulsion Laboratory, under contract No. NAS7-1304. The Government has certain rights in this invention.

FIELD OF THE INVENTION

The present invention relates generally to infrared detectors, and more particularly to detectors for detecting light in the infrared of different wavelengths.

BACKGROUND OF THE INVENTION

Applications involving fiber optic communications systems typically utilize light waves having wavelengths in the near infrared (0.8 to 3.0 micrometers in wavelength). These systems presently represent the greatest usage for near infrared detectors. However, other applications such as temperature sensing, night vision, eye-safe range finding, infrared detectors. However, other applications such as temperature sensing, night vision, eye-safe range finding, infrared detectors. However, other applications such as temperature sensing, night vision, eye-safe range finding, infrared detectors. However, other applications such as temperature sensing, night vision, eye-safe range finding, infrared detectors. However, other applications such as temperature sensing, night vision, eye-safe range finding, infrared detectors. However, other applications such as temperature sensing, night vision, eye-safe range finding, infrared detectors. 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SUMMARY OF THE INVENTION

In one embodiment of the invention, an infrared detector is provided in a plural wavelength InGaAs focal plane array pixel element for detecting a plurality of wavelengths of light over a predetermined range in the infrared or near infrared, where each of the wavelength sensitive detectors are formed on a common substrate, and are individually addressable. The detector consists of successively smaller bandgap layers of In,Ga,,.,As (x=0.53) formed over a substrate, separated by compositionally graded layers of InAs,P,, (y=1) to decrease defects induced by lattice mismatch strain with the InP substrate. Portions of the various layers are selectively removed to form different pn junctions with different wavelength responses, respectively.

BRIEF DESCRIPTION OF THE DRAWINGS

Various embodiments of the present invention are described below with reference to the drawings, in which like items are identified by the same reference designation, and in which:

FIG. 1A is a cross sectional view of an engineering prototype for a three wavelength infrared detector in one embodiment of the invention;

FIG. 1B is a pictorial and chart-like diagram showing for each layer of the device of FIG. 1A, the composition, bandgap, and thickness thereof, respectively;

FIG. 1C is a band diagram positioned in alignment with the corresponding layers of the device of FIG. 1B, for showing the relative bandgaps of each layer compared to the other, respectively;

FIG. 1D shows the bottom of the detector of FIG. 1A, for a preferred embodiment thereof including an antireflective coating and ohmic contact grid thereon;

FIG. 2 shows a plot of the measured dark current of each one of the three detectors of the device of FIG. 1A under various conditions of reverse bias voltage;

FIG. 3 shows a plot of quantum efficiency versus wavelength for each one of the three detector regions of the device of FIG. 1A;

FIG. 4 is a top view of a portion of the device of FIG. 1A, showing three detector regions;

FIG. 5A shows a simplified cross section of the epitaxial structure of an ideal device for another embodiment of the invention;

FIG. 5B shows a band diagram illustrating the band gaps for each one of the corresponding layers of the device of FIG. 5A;

FIG. 6A shows a cross section of the epitaxial structure of an n-color device of another embodiment of the invention; and

FIG. 6B shows a band diagram of the band gaps of each of the layers of the device of FIG. 6A.

DETAILED DESCRIPTION OF THE INVENTION

In FIG. 1A, a prototype detector array pixel sensitive to three different selectable infrared wavelengths is shown, for one embodiment of the invention as developed for use as a focal plane array imaging device for applications such as gas spectroscopy and absolute temperature measurements (pyrometry). Since detectors with smaller bandgap which detect longer wavelength also have larger dark current, one can use this pixel to select the detector with the appropriate absorption layer to maximize the quantum efficiency while minimizing the dark current. The device 1 includes a plurality of integrated detector pixels, each including regions 3, 5, and 7 for detecting different wavelengths of light, respectively. In this example, the light is on the near infrared or infrared wavelength regions. Optical absorption occurs, with reference to FIG. 1B, in 3 μm thick In,0.53Ga0.47As,
InGaAs, InGaAsP, and InGaAs layers 
respectively, were formed in 100 by 150
InP substrate. The lattice parameter of the
InAsP layers immediately above the absorption layers
was determined to be 0.37 nm at room temperature. To fabricate the integrated
InGaAs layers [see FIG. 4], a mixture of 5:1 citric acid (50% by weight)
and H2O2 was used to etch InGaAs detection layers since it is
more chemically inert at room temperature. To etch InAsP layers,
its band diagram in FIG. 1C shows that the band gap and the band offsets between the different
layers 15, 21, 23, 25, 17, 11, 27, 29, 19, 13, and 31, and
FIG. 1B shows the composition, bandgap in electron volts
and equivalent wavelength in micrometers (µm), and the thickness in micrometers (µm), respectively.
A selective wet etching process was developed in order to
access the different absorption layers to enable junction
diffusion for detection regions 3, 5, and 7, respectively (see
FIG. 1A). A mixture of 5:1 citric acid (50% by weight) and 
H2O2 was used to etch InGaAs detection layers since it is
strongly selective of InGaAs (versus InAsP), and leaves
a good surface morphology. The etch rate of InGaAs is
1000 Å/min at room temperature. To etch InAsP layers,
a mixture of HCl:H2O2:H2O2 in the ratio of 3:1:x was used,
where x was varied from 0 to 0.3 as the arsenic concentration in
InAsP was increased. The etch rate of InAsP is ~200
Å/sec at room temperature. To fabricate the integrated
detector array 1, a area square area 33 of 500 µm2 (see FIG. 4) was first etched above the In0.5Ga0.5As layer 11 and In0.5Ga0.5As layer 13, using a plasma deposited SiN film
(1000 Å) as an etch mask, for initially forming detection region 3. Similarly, a 500 µm2 area 34 was etched above
layer 11 for initially forming detector region 5. Thin layers
(1 µm thick) 21 and 27 of InAsP were left on top of the absorption layers in regions 3 and 5 as a wider bandgap cap layer in order to reduce surface-generated dark current. The pn junctions of all three detectors in regions 3, 5, and 7,
respectively, were formed in 100 by 150 µm areas 35, 37, and
39, respectively, using a single sealed ampoule diffusion of 
Zn into the InGaAs layers 21 and 27, as described in FIG. 3A. As
a result, p+ diffusions were formed in regions 35, 37, and 39,
respectively, using a photolithography lift-off process. After, overlay metal contacts 40, 44, and 
46, typically of TiAu material, are formed on top of the 
antireflective coating 41 of SiNx deposited to a thickness of
2250 Å on the top diode surface (see FIG. 1A). Also, 40 µm square Au-Zn alloy contacts 43, 45, and 47 are placed on top of the diffused areas 35, 37, 39, respectively, using a
photolithography lift-off process. Also, overlay metal contacts 40, 44, and 46, typically of TiAu material, are formed on top of the anti-reflection coating 41 in association with detectors 3, 5, and 7, for electrically contacting contacts 43, 45, and 47, respectively. Contacts 43, 45, and 47 facilitate making
electrical connections either to individual ones of, or two or
more of detectors 3, 5, and 7, respectively, using integrated
circuitry techniques, such as flip-chip bonding, or wire bonding.

In order to maximize performance, the back surface of the
detector array 1 or bottom of substrate 15 should preferably
have an antireflection coating 42 of SiNx, and an ohmic
contact grid 48 (typically GeNiAu alloy), as shown in FIG.
1D. More specifically, in the preferred embodiment, the contact 48 is formed into a grid pattern with open spaces 42 for
allowing backlighting or back illumination of the substrate 15 or detector 1. The open spaces 42 consist of a
transparent antireflective coating of SiNx, in this example. Each space 42 permits back illumination of an underlying
absorption layer 9, 11, or 13, associated with a given detector 3, 5, or 7, of a pixel in an array of such pixels, in
this example.

The basic processing steps for the three wavelength
infrared focal plane array detector element 1 of FIG. 1A are summarized in eight steps as follows:
I. Deposit 1.000 Å SiNx film by Plasma Enhanced Chemi-
cal Vapor Deposition (PECVD)
II. Photolithography to define etch area (500 µm square)
III. Material selective wet etching
•InGaAs: Citric Acid:H2O2 at 5:1
•InAsP: HCl:H2O2:H2O2 at 3:1:x
IV. Deposit 1000 Å SiNx diffusion mask
V. Photolithography to define diffusion area (100 by 150 µm area)
VI. Sealed ampoule diffusion using Zn,As3 at 500º C.~350º C. for 20–40 minutes
VII. Deposit 2250 Å SiNx anti-reflective coating on top surface
VIII. Place Au-Zn alloy contacts (40 µm square) on top of diffused area using photore sist lift-off process
IX. Deposit SiNx AR coating on substrate surface
X. Deposit GeNiAu on substrate surface over previously exposed and developed photore sist layer lift off metal
to form grid pattern

Note that in step II, a chrome or iron oxide photolithography
mask can be used. In step III, in place of wet etching, reactive ion (dry) etching can be used. Also, in step IV, a silicon nitride and chrome or iron oxide photolithography mask can be used. Using capacitance versus voltage measurements, the inventors obtained the carrier concentration in the absorption
layers 9, 11, and 13 for each detector 3, 5, and 7, respectively. It was determined that the background carrier
concentration in the absorption layers 11 and 13 is ~<1x1016
cm-3, but higher for the In0.53Ga0.47As layer 9 where the carrier concentration increases near the heavily doped
substrate 15, due to the diffusion of the sulfur substrate dopant into the epitaxially grown layer. Also, at 0 V, the smaller bandgap materials have higher capacitance (2.1, 3.0, 7.8 pF
for In0.53Ga0.47As, In0.53Ga0.47As, and In0.53Ga0.47As layers
9, 11, and 13, respectively). In the operation range of 5–10
V, all diodes or pn junctions exhibit capacitances ranging
from 1.2–2.0 pF, again with the short wavelength (In0.53Ga0.47As) detector 3 having the smallest capacitance.
The dark current of each detector 3, 5, and 7 under reverse
bias is shown as points in FIG. 2, in plots 49, 51, and 53, for absorption layers 9, 11, and 13, respectively. The error bars
were determined from the sum of measurement random error (determined to be five percent of the measured value)
and small systematic errors. The lines are theoretical fits assuming that the total dark current is the sum of the
generation-recombination current (either in the bulk or at
the surface), junction shunt current, and diffusion current at low
voltage, while tunneling dominates at high voltages, as has been shown to be the case in previous studies of InGaAs photodiodes.

The theory fits the measured data, especially for the InGaAs detector. The dark current for this detector is generation-recombination current which is (at V=kT) given by:

\[ I_{\text{dark}} = \frac{q n_e W}{\tau_{\text{eff}}} \]

where \( k \) is the Boltzmann constant, \( T \) is the absolute temperature, \( q \) is the electronic charge, \( \tau_{\text{eff}} \) is the effective carrier lifetime, \( n_e \) is the intrinsic carrier concentration, \( A \) is the surface or cross-sectional area of the depletion region boundary, and \( W \) is the depletion region width for an abrupt one-sided junction. From the fit, the value of \( \tau_{\text{eff}} \) is estimated to be 1 \( \mu \)s, indicating that the growth and processing of the complex structure shown in FIG. 1 does not significantly affect the diode properties. The tunneling current, which becomes dominant at \( V > 15 \) volts for this detector, is given by:

\[ I_{\text{tunnel}} = \frac{q n_e W}{\tau_{\text{eff}}} \sqrt{\frac{2}{\pi}} \frac{E_m}{\cos \theta_m} \]

where \( m_e \) is the free electron mass, \( E_m \) is the energy band gap of the absorbing layer material, \( \theta_m \) is Planck's constant divided by \( 2\pi \), and \( E_m \) is the maximum junction electric field given by:

\[ E_m = V \left( V - V_b \right) \]

and \( \Theta \) depends on the shape of the tunneling barrier. Here, \( \Theta \) was estimated to be 0.26 from the fit. The prefactor \( \gamma \) depends on the initial and final states of the tunneling states.

The dark currents of InGaAs and InGaAs detectors 5 and 7, respectively, are considerably larger than for the InGaAs detector, especially at low voltages. This is due, in part, to the smaller bandgap of the former materials which not only leads to an increased intrinsic carrier concentration affecting both the diffusion and the generation-recombination currents, but also leads to increased tunneling current. Another source of the high dark current is the larger concentration of defects in these materials caused by the lattice mismatch between the absorption layers and the InP substrate. These defects provide midgap generation-recombination centers, increasing the generation-recombination current. Indeed, \( \tau_{\text{eff}} \) for the InGaAs detector is estimated to be 110 ns, which is nearly an order of magnitude less than for InGaAs detectors 9.

The a.c. small signal conductance at 0 V was measured at 1 kHz to be 18.2 nS, 4.54 \( \mu \)S, and 9.24 \( \mu \)S which translates to unshunt resistances of 55.1 M\( \Omega \), 220 k\( \Omega \), and 107 k\( \Omega \) for InGaAs layer 9, InGaAs layer 11, and InGaAs layer 13 for detectors 5 and 7, respectively. Assuming that the generation-recombination is the main source of conductance near 0 V, one can calculate \( \tau_{\text{eff}} \) (using these conductance values) for InGaAs layers and InGaAs layers 9, 11, respectively, to be 1.1 \( \mu \)s and 61 ns, which is in good agreement with values calculated from the dark current.

The contribution from shunt current, given by:

\[ I_{\text{shunt}} = V R_{\text{shunt}} \]

where \( R_{\text{shunt}} \) is the effective resistance, was found to be much greater for InGaAs and InGaAs detectors, where \( R_{\text{shunt}} \) was approximately 3-4 M\( \Omega \), for InGaAs detector, \( R_{\text{shunt}} \) is 5 \( \Omega \). This may also be due to the larger number of defects in the InGaAs and InGaAs layers, but the physical origin of the shunt conduction is not clear.

The diffusion current is negligible except for the InGaAs detector. The diffusion current is given by:

\[ I_{\text{diff}} = \frac{q n_e W}{\tau_{\text{diff}}} \sqrt{\frac{2}{\pi}} \frac{E_m}{\cos \theta_m} \]

where \( D \) is the hole diffusion constant, \( \tau_{\text{diff}} \) is the minority carrier diffusion lifetime, and \( N_e \) is the doping density. The diffusion current depends exponentially on the bandgap which is smallest for the InGaAs layer 13, where \( \tau_{\text{diff}} \) was estimated to be 500 ps.

Note that the tunneling current contribution to the dark current was not observed for the InGaAs and InGaAs detectors 5 and 7 due to the large component of generation, diffusion, and shunt currents. It is believed that the integration and processing of the three-detector pixel in the above example for detector array 1 does not significantly degrade individual device performance.

The quantum efficiency of each detector 3, 5, and 7 under front (light incident from the associated pn junction) and back illumination is shown in plots 55, 57, and 59, respectively, of FIG. 3. The measurements were made under a reverse bias of 3.5, 6.0, 5.0 volts for InGaAs, InGaAs, and InGaAs detectors 3, 5, and 7, respectively. The measured long wavelength cutoffs of 1.7, 2.1, and 2.5 \( \mu \)m correspond to the bandgaps of the absorption layer materials. The short wavelength cutoff for the device 1 under back illumination is determined by the light absorption properties of layers between the substrate 15 and the absorption layers 9, 11, and 13. For example, for the InGaAs layer forming detector 5, light absorbed in the underlying InGaAs layer 9 will not be detected, thus the short wavelength cutoff of the InGaAs detector 5 is approximately equal to the cutoff wavelength of InGaAs layer 9. The peak quantum efficiency under front illumination ranges from 55 to 95%. For the InGaAs detector 7, the peak quantum efficiency was determined to be 55%. This lower than expected efficiency is believed due, in part, to the large number of heterojunctions and layers underlying the detectors, increasing the probability of the carrier being captured and recombining at traps prior to being collected. Also, the fact that the diffusion of \( Zn \) is faster for InGaAs compared with InGaAs layer 13 compared with the other absorption layers 9 and 11, caused the thickness of the depleted absorption region to be less than optimum (<2 \( \mu \)m) in this detector 1, affecting its quantum efficiency. The peak quantum efficiency under back illumination (between 15% and 60%) is somewhat lower than for front illumination since the antireflective coating was deposited only on the top surface of device 1, in this particular example.

In summary of one embodiment of the invention, as described above, a novel three wavelength InGaAs focal plane array pixel element 1 for detector at wavelengths from 0.9-2.6 \( \mu \)m is shown, where each of three wavelength-sensitive detectors 3, 5, and 7 are individually addressable. This device 1 consists of successively smaller bandgap layers of InGaAs (x=0.53) 9, 11, and 13, grown on an InP substrate 15, separated by layers of InAsP to decrease defects induced by lattice mismatch strain with the substrate 15. The various layers were selectively removed so thatpn junctions with different wavelength response can be
separately contacted. All three detectors 3, 5, and 7 have quantum efficiencies between 15 and 95% (depending on wavelength and illumination direction) and dark currents from 0.01 to 10 mA/cm²—values comparable to discrete photodiodes with similar wavelength responses.

To improve the performance of the three wavelength infrared focal plane array detector 1 of FIGS. 1A, and 1B, the present inventors believe that the modified device as shown in FIG. 5A is preferred. As shown, relative to the prototype detector element 1 of FIG. 1B, the preferred embodiment thereof of FIG. 5A includes an additional transparent strain relief layer 18 between absorption layer 11 and strain relief layer 27, as shown. Improved performance is expected to be obtained in that the lattice parameter of the InGaAsP or InAlAsSb layers 17 and 18, immediately below and above the absorption layer 11, are matched. In this manner, the magnitude of the dark current associated with absorption layer 11 is expected to be reduced, as previously indicated above. Also, the improved performance can be observed by comparing the band diagram shown in FIG. 1C for the prototype device 1, relative to the band diagram of FIG. 5B for the preferred configuration of FIG. 5A, whereby as shown the bandgap is extended for strain relief layers 19, 29 and 27, by the addition of strain relief layer 18.

The present invention, within practical limits, can be extended to provide a focal plane array detector element capable of detecting "N" different wavelengths, where N is any integer number 1, 2, 3, 4, 5, . . . . N. As shown in FIG. 6A, such a device includes a cap layer 62, analogous to layer 31 of FIG. 5A, a substrate 50, a first absorption layer 52, under strain relief layers 54 (analogous to layers 17, 25, 23, and 21 of the device of FIG. 5A), a second absorption layer 56, followed by alternating buffer absorption layers 58 to the Nth order or degree, followed by an Nth absorption layer, followed by the previously mentioned cap layer 62. The material for each of these layers is generally indicated in Table 1 shown below, as is the doping for each of these layers. Also, in FIG. 6B a band diagram is included showing the bandgaps of the various layers associated with the N absorption layer device of FIG. 6A.

<table>
<thead>
<tr>
<th>Layer</th>
<th>Name</th>
<th>Material</th>
<th>Doping</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>Substrate</td>
<td>InP</td>
<td>n-</td>
</tr>
<tr>
<td>52</td>
<td>First Absorption Layer</td>
<td>InGaAs</td>
<td>Undoped (n-)</td>
</tr>
<tr>
<td>54</td>
<td>Buffer Layers</td>
<td>InAsP, GaAlAsSb, InGaP, InGaAsSb, or InGaAs</td>
<td>Undoped (n-)</td>
</tr>
<tr>
<td>56</td>
<td>Second Absorption Layer</td>
<td>InGaAs</td>
<td>Undoped (n-)</td>
</tr>
<tr>
<td>58</td>
<td>Alternating Buffer and Absorption Layers</td>
<td>InGaAs</td>
<td>Undoped (n-)</td>
</tr>
<tr>
<td>60</td>
<td>Nth Absorption Layer</td>
<td>InGaAs</td>
<td>Undoped (n-)</td>
</tr>
<tr>
<td>62</td>
<td>Cap Layer</td>
<td>Same as Layer C</td>
<td>Undoped (n-)</td>
</tr>
</tbody>
</table>

Although various embodiments of the invention are described herein for purposes of illustration, they are not meant to be limiting. Those of skill in the art may recognize modifications that can be made in the illustrated embodiments. Such modifications are meant to be covered by the spirit and scope of the appended claims. For example, a plurality of pixels each providing the capability of detecting up to (N+1) different wavelengths of light can be provided on a common substrate, with each pixel including (N+1) detectors, thereby providing an array of such pixels through use of the present invention.

What is claimed is:

1. A multiwavelength focal plane array light detector, comprising:
   a substrate doped to have a first conductivity, said substrate having top and bottom faces;
   a plurality of (N+1) absorption layers formed over the top of said substrate, where N=1, 2, 3, 4, . . . , the composition of each of said plurality of absorption layers being individually predetermined for absorbing or detecting different wavelengths of light, respectively;
   a plurality of (N−1) groups of light transparent buffer layers sandwiched between each successive pair of said plurality of (N+1) absorption layers, each of said groups of buffer layers including a plurality of buffer layers, said buffer layers of each group having successively decreasing bandgaps, the further a buffer layer is from said substrate relative to other buffer layers of its associated group of buffer layers, and at least all but one buffer layer of each said group of buffer layers having smaller bandgaps than the buffer layers of any other of said groups of said buffer layers closer to said substrate, respectively, relative to said substrate, for substantially preventing lattice mismatch dislocations from propagating through successive ones of said plurality of absorption layers, said buffer layers each having said first conductivity;
   a plurality of spaced apart holes formed from a top of said detector through selected successive ones of said absorption layers and buffer layers, for exposing predetermined areas of top portions of successive ones of said absorption layers, respectively, of said exposed areas of said absorption layers being doped to form an underlying region in the associated absorption layer having a second conductivity opposite that of said first conductivity;
   a plurality of first ohmic contacts individually formed in a portion of the holes and on top of a portion of each of said exposed areas of said absorption layers; and
   a second ohmic contact formed on the bottom of said substrate, whereby a plurality of light detecting diodes are provided relative to each exposed area of said absorption layers, respectively, for individually detecting light of different wavelengths, respectively.

2. The light detector of claim 1, wherein for each successive second through (1+Nth) absorption layer, the same lattice parameter is provided for the ones of said absorption layers and buffer layers, for individually detecting light of different wavelengths, respectively.

3. The light detector of claim 1, further including:
   an antireflective coating on top and bottom faces thereof exclusive of said plurality of first ohmic contacts, and said second ohmic contact, respectively.

4. The light detector of claim 1, further including a transparent capping layer of buffer layer material formed over top portions of said detector exclusive of said exposed areas of said absorption layers, respectively.

5. The light detector of claim 4, further including:
   an antireflective coating on topmost and bottommost faces of said detector exclusive of said plurality of first ohmic contacts, and said second ohmic contact.

6. The light detector of claim 1, wherein said plurality of (N+1) absorption layers consist of In,Ga,−xAs (X=0.53), whereby beginning with N=1 for first and second absorption layers formed over said substrate, and succeeding (N+1)
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ones of said absorption layers, each have successively decreasing bandgaps relative to said substrate, respectively, for detecting successively increasing or longer wavelengths of light.

7. The light detector of claim 6, wherein said plurality of N buffer layers consist of InAs$_x$P$_{1-x}$ material where $y \leq 1$.

8. The light detector of claim 7, wherein said substrate consists of InP material.

9. The light detector of claim 8, wherein each one of said plurality of (N+1) absorption layers is sandwiched between two of said buffer layers of substantially the same composition, whereby a first one of said absorption layers formed directly over said InP substrate, is covered by a buffer layer of InP material substantially the same as that of said substrate.

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