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Integrated HBT/QWIP structure for dual color imaging

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Abstract

An integrated two-terminal structure of quantum well infrared photodetector (QWIP) and heterojunction bipolar phototransistor (HBT) for dual band imaging is presented. The integrated device functions as a voltage switchable dual band detector for long wavelength infrared (LWIR) and near infrared (NIR) imaging. The device consists of series integration of floating base HBT and a QWIP in a two terminal configuration. Switching between the two spectral bands is achieved by changing the applied bias voltage. At a low bias voltage the HBT operates in the saturation mode and, due to its higher impedance, it is the only portion of the device that responds to NIR radiation. With the increasing bias voltage the HBT enter the breakdown region to activate the operation of the QWIP as LWIR detector.

In order to achieve NIR response up to about 1.064 μm, strained layers of InGaAs/GaAs quantum wells were implemented in the sub-collector of the HBT. The NIR photocurrent acts as the base current of the HBT and is amplified inherently by the transistor gain. Furthermore, the breakdown of the HBT is designed to follow the punch-through mode so that one can engineer the breakdown voltage to be of the order of a few volts. In addition, this mode allows fast, reliable and nondestructive switching of the integrated device. Standard design of GaAs/AlGaAs QWIPs layers have been used to achieve LWIR detection.

The integrated device, which is based on the GaAs technology, allows fabrication of large focal plane array (FPA) that can be operated using a commercial two-terminal readout integrated circuit (ROIC). Such FPA configuration would allow multispectral applications such as simultaneous imaging of a NIR laser spot superimposed on a thermal imaging scene (SEE SPOT).

Keywords: QWIP; Dual color; LWIR; NIR; HBT; SEE SPOT

1. Introduction

During the last years we are witnessed to an increasing demand for multispectral detectors and imaging systems. Most of the effort is focused

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on development of devices combining several bands between and within the MWIR and LWIR spectral regimes [1–4]. This kind of detectors is used in multispectral passive imaging systems. In those systems the additional spectral information is usually used for better separation between target and background using various algorithms. Another family of multispectral detectors and application is based on combination of NIR and either MWIR or LWIR [5]. Natural objects in ambient temperature of around 300 K emit MWIR and especially LWIR radiation. NIR radiation is emitted from active sources like the Sun or other "hot" illuminators. For any application that requires collocated and simultaneous information from active and passive sources of radiation, the best solution would be a monolithic NIR/MWIR or NIR/LWIR focal plane array. Using a monolithic structure guaranties optimal registration between the different spectral data sources, and avoids misinterpretation of the information. On the other hand in order to be able to use the information correctly, signals from the different spectral regimes should be separated. Signal separation could be done using a three terminal ROIC. Using this kind of solution makes the fabrication process of the device more complex, and requires a more complicated ROIC. In this work we demonstrate a monolithic GaAs/AlGaAs/InGaAs device for NIR and LWIR detection in a novel structure. The device has relatively high sensitivity for the two spectral bands and allows switching between them using a commercial two terminal ROIC.

2. Device concept

The device is based on GaAs due to the maturity of this technology. The device combines two sensing mechanisms—inter subband transitions (ISBT) for the LWIR detection, and inter band transitions (IBT) for the NIR detection. The device is a combination of standard n type GaAs/AlGaAs QWIP with peak wavelength response at 8800 nm, and intrinsic InGaAs/GaAs quantum wells for NIR detection. In order to detect NIR radiation at wavelengths above 850 nm, InGaAs layers should be used. Increasing the indium content decreases the band gap and therefore increases the cutoff wavelength of the device. Due to the difference between the GaAs and the InGaAs lattice constants, the structure is under strain. In order to avoid strain relaxation the InGaAs layers width should not exceed the critical thickness [6,7]. Therefore, even though the NIR detection mechanism is based on interband transitions, quantum wells are used also in this portion of the device.

In order to collocate the LWIR and the NIR radiation, and to avoid miss registration problems, a two stacks structure is used. The two stacks structure, together with appropriate optical design, guaranties that each pixel of the FPA will collect all the spectral information radiated from an instantaneous area of interest.

In order to switch between the NIR and the LWIR detectors and separating the signals, the NIR detecting layers are embedded within a HBT device. The HBT is a n-p-i-n structure, with n type AlGaAs emitter, p type GaAs base and n type GaAs collector. The intrinsic InGaAs thin layers are located between the base and the collector. Energy band diagram of the HBT is shown in Fig. 1.

Since there is no contact to the base, the HBT device is functioning in a floating base mode. The NIR photo current replaces the base current. As illustrated in Fig. 1, when a NIR photon with appropriate wavelength is absorbed in the device, an electron hole pair is generated in the intrinsic portion of the device. The generated electrons are swept by the built in electric field towards the collector, creating photocurrent. Due to the discontinuity of the emitter and the base energy bands, the swept holes are accumulated within the base area. Those holes generate the transistor gain—β that can be approximated as the ratio between the collector current and the base current. Since in our case the base current and the photocurrent are identical, β is simply the photo current gain.

In addition to the gain, the HBT structure allows switching, which is based on breakdown process. The breakdown process in this case is punch through, and it occurs when the emitter collector bias is raised so that the two depletion layers of