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Van Hove singularities in intersubband transitions in multiquantum well photodetectors

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Abstract

High dynamics measurements of spectral response were carried out on quantum well infrared photodetectors (QWIP). Photocurrent spectra were studied over more than three orders of magnitude, revealing the presence of spectral structures which were never observed hitherto. Electric field assisted tunneling and, more surprisingly, Van Hove singularities at the miniband edges, are shown to play an important role in the low and high energy parts of the QWIP photocurrent spectra, respectively. These experimental features motivated us to initiate a theoretical study of the absorption in a multiquantum well structure. Our work is based on the study of the electronic wave function in a periodic structure.

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Keywords: Quantum well infrared photodetectors; Photocurrent spectra; Van Hove singularities; Electric field assisted tunneling

1. Introduction

Multiquantum well infrared photodetectors (QWIPs) are now a mature technology, for large infrared focal plane arrays [1–4]. One of the potential of this technology, is the possibility of multispectral detection, thanks to stacked structures with different growth parameters [5]. For this purpose, it is very important to determine and understand the photoresponse of QWIPs with a great accuracy far from their peak responsivity. Indeed, this will allow one to evaluate the possible cross talk between the signals originating from different detected infrared bands (3–5 μm and 8–12 μm for instance). However, mainly because of experimental difficulties, very little effort has been devoted to measure and modelling these off-band responsivities with sufficient dynamical range. In this article, we describe an experiment (referred as Log spectra in the text) which allows these measurements. Thanks to the large dynamical range, these Log spectra show that the off band spectral responsivity of QWIPs is largely influenced by quantum effects such as electric field assisted tunnelling for the low energy side and, rather unexpectedly, by Van Hove singularities due to the quantum well periodicity for the high energy side.

Section 2 describes the test bench dedicated to the spectral response measurements and the detectors under study. The experimental results are then compared to our model, based on a Kronig–Penney approach (see Section 3.1).

2. Experimental photocurrent spectra of a single element QWIP

2.1. Experimental setup

Fig. 1 presents the technique developed at ONERA to perform spectral studies. It is based on the use of a

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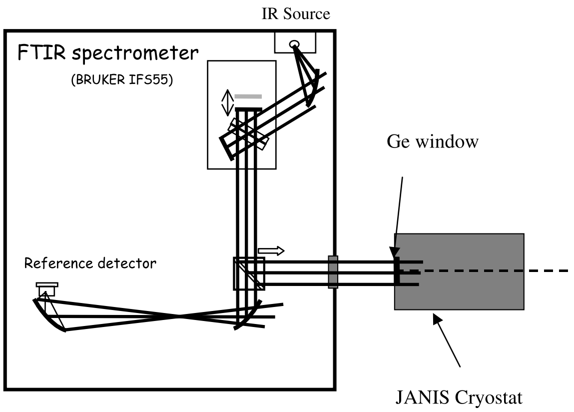

Fig. 1. ONERA experimental setup for the measurements of spectral response.

commercial FTIR spectrometer. The QWIP is mounted in a JANIS continuous flow helium cryostat placed outside a Fourier transform infrared spectrometer (FTIR). The commercial FTIR (Bruker, Equinox IFS55) produces either a reference spectrum (thanks to an internal reference detector with a known spectral response), or an external collimated beam of uniform intensity which is used to illuminate the detector. The angle of incidence on the sample may be adjusted from normal incidence to ±50° [6]. In fact the detector is put on a cold disc which is tilted with respect to the coldfinger with an angle of 50° in order to increase the signal noise ratio (see Fig. 2). The time-dependent signal delivered by the detector in response to the time-varying interferogram is amplified (Keithley 428) and sent to a series of pass-band filters to get rid of noise. It is then sent to the spectrometer for Fourier transformation and normalization by the reference spectrum. The spectral emission of the internal source, the reference detector response and the transmission of the cryostat germanium window are taken into account in our measurements.

Limiting the experimental noise is a crucial issue in such high dynamics measurements. Therefore, all electrical wires are protected inside and outside the cryostat. Thus we can assure a low noise experimental setup. The repeatability of our measures also indicates that the features observed on the QWIP spectral response are not artefacts.

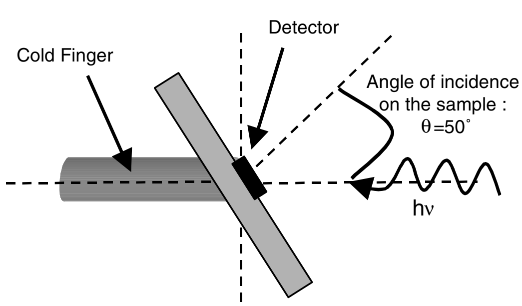

Fig. 2. Position of the detector in the cryogenic assembly.

2.2. Samples under study and operating conditions

The measurements presented in this paper were realized on QWIP single elements provided by Thales – Research and Technology laboratory. The peak wavelength of the 100 μm × 100 μm pixels is 8.5 μm. They consist in 40 GaAs quantum wells, 5 nm thick with 35 nm $Al_{0.26}Ga_{0.74}As$ barriers. The structure was designed so that the first excited state is quasi-bound in the well. The following results would nevertheless apply to bound-to-extended transitions. Bound to bound transitions are more complex because of additional phenomena, such as sequential tunnelling [7]. Mesas are defined by reactive ion etching. In order to determine the intrinsic spectral responsivity of the QWIPs, we worked with samples without any grating coupling.

The photodetectors are located on the coldfinger of the cryogenic assembly (see Fig. 2). Although the typical operating temperature is 70–75 K [8] for this kind of components in high performance cameras, we resorted to use a lower operating temperature of 40 K for our experiment, in order to decrease the dark current.

2.3. Experimental results

Fig. 3 shows the Log spectra of QWIPs for different applied biases. For comparison purpose, the spectra are normalized to their peak responsivities. This figure illustrates the good dynamical range of our measurements since three orders of magnitude are explored thanks to our low noise experimental setup. The main features of the figures are the following: Firstly, the experiment confirms the non negligible off-band response of the QWIP in the 3–5 μm window compared to its resonance value (still 1% in the 3–5 μm range). This value, however, is likely to be attenuated using coupling gratings. Secondly the low energy side of the spectral response is strongly affected by the applied electric field while the high energy side shows little dependence. Finally, rather sharp features are

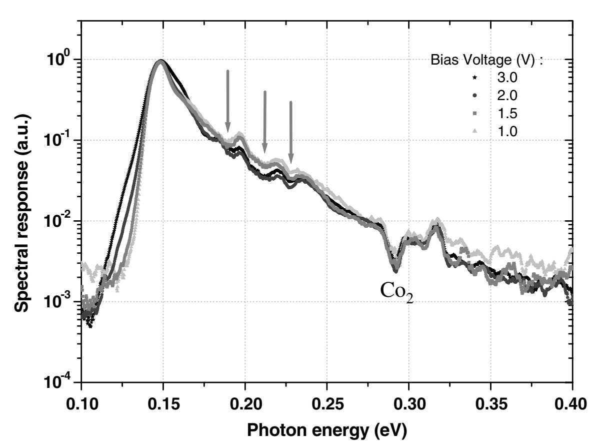

Fig. 3. Experimental Log photocurrent spectra of typical QWIP samples for different applied electric fields (1 V, 1.5 V, 2 V, 3 V). Note the influence of the electric field in the low energy part and the sharp features indicated by continuous arrows in the high energy part.