行政院國家科學委員會專題研究計畫執行進度報告

超晶格紅外線偵測器及發光二極體之研究
Study on Superlattice Infrared Photodetectors and Emitting Diodes

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一、中文摘要

在本子計畫中，我們將發展光電流雜訊的量測技術來研究這些區域性能階的光電特性；尤其是它們對導電帶電子及價電帶電洞等生命期的影響。這些參數是設計雷射及偵檢器等元件的重要參數。單靠簡單的 I-V 或光譜量測是無法得知生命期的大小；但它們卻反應在光電流的雜訊上。由量測元件光電流的雜訊功率，求其與 $4eI_{ph}$(I_{ph} 為光電流)的比值，可得到雜訊電流增益。該值為載子生命期與過渡時間之比。過渡時間為載子經過樣本所需的時間，可以藉由改變樣本大小或外加電壓值而調整。如此由雜訊電流增益所求得生命期的最小值，可以不受限於儀器的頻率分析能力，此為整套系統最大的優點。

本子計畫預計以二年的時間持續發展此光電流雜訊量測技術，所針對的元件分別為 GaN bulk、量子井及點、具有 C-base 的奈微米結構。其中的 GaN bulk 是研究其雜質或者是 defects 所造成的區域性能階；而其他的則是結構所導致的區域性能階。除了量測光電流雜訊外，我們也將針對各元件進行 FTIR 紅外線吸收光譜實驗、photoluminescence 實驗、拉曼吸收光譜實驗、以及 step scan FTIR 發射光譜實驗。綜合各實驗所得的結果，以便瞭解生命期中 radiative transition 與 nonradiative transition 的相對大小，以及造成 nonradiative transition 的主要原因。在未來的計畫中，我們將沿用這些成果，持續發展利用奈微米結構所設計出的光電元件。

關鍵詞：區域性能階、奈微米結構、量子井、量子點、雜訊量測

二、英文摘要

In this proposal, we will develop a technique to measure the noise power of the photocurrent to investigate the localized states. In particular, the associated lifetime of the free carriers with the localized states is our primary interest. The carrier lifetime is an important parameter for those devices such as laser diodes and detectors. With simple measurement of I-V characteristics or absorption spectrum, we can not determine its value. However, it can be derived from the noise power of the photocurrent in the devices. The ratio of the photocurrent noise power over $4eI_{ph}$ where I_{ph} is the photocurrent gives the noise current gain. The noise current gain also equals the ratio of the lifetime over the transit time. In average, a free carrier passes through the sample in a transit time. Its magnitude may be changed with the sample length or the applied voltage. Therefore, the lifetime measured with the photocurrent noise is not limited by the frequency capability of the measurement system. This is the best advantage of this method to measure the carrier lifetime.

In the future three years, we will keep going on the development of the measurement technique of the photocurrent noise. The devices we will investigate are involved with the GaN bulk, quantum wells, quantum dots, or C-base nanostructures. For the GaN bulk, we will study the localized states caused by the

impurities and defects while for the others, the localized states by the nanostructures. In addition to the noise measurement, we will also proceed the measurements of the FTIR absorption spectrum, photoluminescence, Raman absorption spectrum, and step scan radiation spectrum. Based on all the experimental results, the lifetime can be analyzed for which of the radiative or nonradiative transitions is more important. In particular, the mechanism rendering the nonradiative transition is our primary concern. In the future plan, all of the results derived from this proposal will be utilized to design the optoelectronic devices with such nanostructures.

Keywords: localized state, nanostructure, quantum well, quantum dot, noise measurement.

三、計畫緣由與目的

半導體中之區域性能階常出現在能量帶溝中，其所產生的原因可起源於雜質、defect、量子井、量子點、甚至是植入的奈微米結構。這些能階會補捉導電帶的電子或價電帶的電洞，因而影響半導體的載子傳遞及放光吸光特性，若能藉用它們的影響，則可設計製作出更多具有變異性的光電元件，例如雷射、光偵檢器等。

四、執行進度

The noise characteristics are an important factor to determine the performance of an infrared photodetector, especially the noise equivalent differential temperature and the detectivity. In this paper, we report the 77K noise characteristics of an infrared hot-electron transistor (IHET) whose sample structure is shown in Fig. 1. The IHET contains a multiple quantum well photodetector (QWIP) between the emitter and the base, and a double barrier energy filter between the base and the collector.

In the noise measurement, the QWIP is under a fixed bias V_{BE} while the base and the collector are kept at the same ground potential (see Fig.1). The background noise from the measurement set-up is well calibrated and subtracted to get the noise power from the IHET. The emitter noise power (S_E) measured from the emitter current (I_E) represents the noise characteristics of the QWIP structure. The collector noise power (S_C) measured from the collector current (I_C) is the noise behavior of hot electrons injected from the QWIP and tunneling through the energy filter. The solid circles in Fig. 2 and 3 are the experimental results of S_E and S_C respectively. In addition, we also measure the dark currents (I_E and I_C), the emitter photocurrent gain g and the emitter differential conductance G at 77K.

At 77K, the dominant current in the QWIP is due to the electrons excited by thermally assisted tunneling. These electrons, travelling above the barriers and scattered by phonons or impurities, are finally trapped into another quantum well. The noise due to the thermal excitation and the trapping by quantum wells is similar to the generation-recombination noise (G-R noise) in the photoconductor. The noise power due to this mechanism[1] can be written as $4egI_E$. The reason we use the photocurrent gain is because the thermal excitation is similar to the photon excitation. The dash-dot line in Fig. 2 is the G-R noise power. Besides, the scattering process is also a noise source which is similar to the thermal noise in a conductor. This thermal noise power is 4kTG and also shown as dashed line in Fig. 2. Suppose the thermal noise and the G-R noise are independent. The sum of these two noise power is shown as the solid curve in Fig. 2 and agrees well with the experimental data. At low biases, the thermal noise is dominant since the electric field within the barriers is weak and the current gain is small. When the bias is larger than 2.5V, the G-R noise becomes more important.

In the collector, the shot noise power, $2eI_C$, is estimated and compared with the experimental data. They agree with each other very well up to V_{BE} = 5V. According to binomial statistics, if the probability when an event occurs is much less than 1, the variance, σ^2, of the number of the event is equal to its average number.[2] Suppose the event is the tunneling of the injected hot electrons through the energy filter. Assume the minimum measurement time is τ and the average number of the tunneling electrons within τ is N. The relation between N and I_C is $I_C = eN/\tau$. Then the noise power is $e^2\sigma^2/(B\tau^2)= 2eI_C$ where $B=1/(2\tau)$ is measurement bandwidth. We also measure the transfer ratio α (= I_C/I_E) and find $\alpha < 0.04$ up to V_{BE} = 5V. This confirms that the tunneling probability is small and the collector noise is a shot noise.

In summary, we measure and study the emitter and collector noise of an IHET, and find that the QWIP noise can be described as the sum of the thermal noise and G-R noise while the collector noise is a shot noise when the tunneling probability through the energy filter is much less than 1.

五、圖表及註解

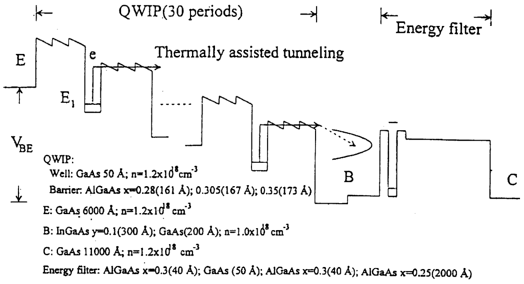

Fig. 1 The sample strucure of the infrared hot-electron transistor and its band diagram under a fixed bias VBE.

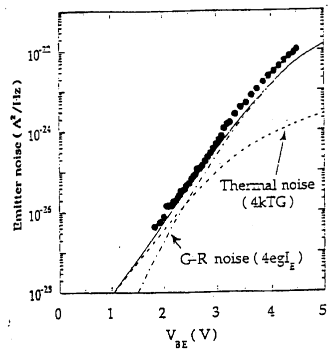

Fig. 2 Emitter noise power (solid circles) versus V_{BE}. The dash-dot line is the estimatedgeneration-recombination noise power and the dashed line is the thermal noise power. Thesolid line is the sum of the two noise powers.

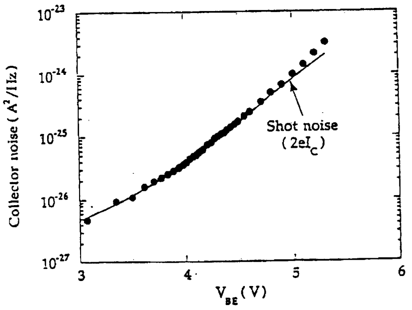

Fig. 3 Collector noise power (solid circles) versus V_{BE}. The solid line is the estimated shot noise power.

六、參考文獻

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