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Temperature Dependence of QCSE Device Characteristics and Performance

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I. Introduction

Multiple quantum well (MQW) devices based on the quantum-confined Stark effect (QCSE) occupy a prominent place in the development of smart pixel technologies. The devices are typically p-i(MQW)-n diodes which can perform the function of a modulator or detector. The devices may be operated in reflection mode, where reflecting mirror layers are grown atop the device, which is then flip-chip bonded onto a silicon CMOS chip. For GaAs/AlGaAs devices operating near 850 nm, substrate removal is a necessary final step in the hybridization process. [1]

Active control of the die temperature results in it becoming a free operating parameter. It will be shown that, through active control of device temperature, MQW devices can be operated efficiently over wide ranges in operating parameters.

Analysis was performed on data obtained from MQW device samples consisting of 90 Å GaAs wells and 35 Å AlGaAs (40% Al mole ratio) barriers. The devices have 60 wells, for an active region thickness of 0.75 μm. Absorption spectra were measured before the reflecting mirror layers had been grown and before flip chip bonding. The data were taken as a function of reverse bias, wavelength, and temperature, and then used to calculate derived MQW device characteristics for the case of a flip-chipped device with reflecting mirror layers.

II. Characteristics of QCSE Devices

The main characteristic in the absorption spectra of a MQW device is the exciton absorption peak. The strength of the peak is denoted as α_{MQW}. The wavelength position of the peak is denoted as λ_o at zero-bias, and λ_p at an arbitrary bias. λ_o and λ_p are dependent on the band-gap energy of the well material, and thus shift to longer wavelengths with increasing temperature. For the MQW samples, the measured shift was 0.241 nm/K, which is in close agreement with [3].

The QCSE [2] is a means by which efficient, high-speed modulation of λ_p can be achieved. The application of an electric field perpendicular to the quantum well layers results in a shift of λ_p to longer wavelengths. Associated with the wavelength shift of the QCSE is a reduction in α_{MQW}, both of which are approximately quadratic with applied field.

III. Principles of Operation of QCSE Devices

QCSE Reflection Modulators

The normal method of operation for a QCSE reflection modulator is $\lambda_o < \lambda_{op}$, where λ_{op} is the device operating wavelength, taken as 852 nm for the analysis in this paper. Modulation in the intensity of a reference optical beam is achieved by shifting λ_p toward λ_{op} to achieve low reflectivity, and by shifting λ_p away from λ_{op} to achieve high reflectivity. Shifting is usually achieved by utilizing the QCSE, but can also be achieved by changing the operating temperature of the device.

With $\lambda_o < \lambda_{op}$, a pre-bias voltage, V_{pb}, corresponds to the high reflectivity state, and a high reverse-bias, $V_{pb} + V_{sw}$, corresponds to the low reflectivity state. V_{sw} is the voltage swing provided by the drive electronics, which is taken as 5 V for the analysis in this paper.

The figure of merit for a QCSE modulator is its change in reflectivity from the low state to the high state [3]:

$$\eta_{\text{modulator}} = \Delta R = R(V_{pb}) - R(V_{pb} + V_{sw}) \quad (1)$$

The efficiency of a MQW modulator depends greatly on the relative positions of λ_o and λ_{op}. Following [4], we define $\delta\lambda = \lambda_{op} - \lambda_o$. Furthermore, we define $\Delta\lambda$ as the wavelength shift that is achieved when a reverse bias of $V_{pb} + V_{sw}$ is applied. For efficient operation of the modulator, one requires $\delta\lambda \approx \Delta\lambda$. This can be achieved by changing the parameters of the usually by adjusting V_{pb}. However, it is not always advantageous to do so. For example, if $\delta\lambda >> \Delta\lambda$, a large increase in V_{pb} may be required, and the resulting reduction in α_{MQW} may overcome the benefits of operating in the $\delta\lambda \approx \Delta\lambda$ regime. If $\delta\lambda << \Delta\lambda$, a significant reduction in V_{pb} may be required, which may be incompatible with

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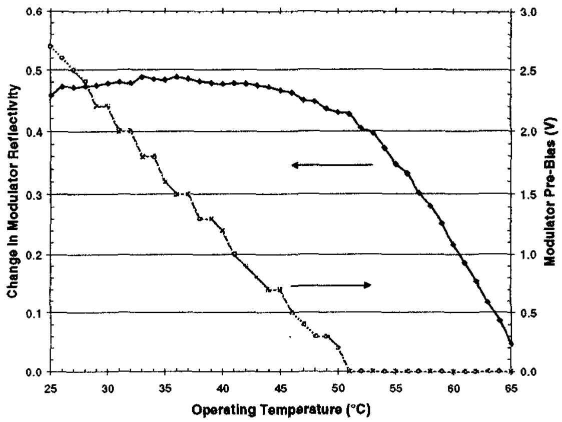

Figure 1 – Optimal ΔR versus T_{op}

the requirement that V_{pb} be positive. Under either of these circumstances, the alternative to modifying V_{pb} is to modify the operating temperature, T_{op}.

Figure 1 shows the optimal ΔR (with the corresponding optimal V_{pb}) plotted versus T_{op}. At 51°C, the optimal V_{pb} becomes 0, and the efficiency of the modulator decreases rapidly with increasing T_{op}. At the low end of the temperature axis, the efficiency begins to slowly decrease, indicating that the reduction in α_{MQW} due to the large V_{pb} is starting to dominate.

QCSE Detectors

As for QCSE modulators, QCSE detectors are typically designed such that $\lambda_o < \lambda_{op}$. The objective of the detector is to convert incident optical power into photocurrent as efficiently as possible, so the figure of merit for a detector is simply quantum efficiency [3]. To optimize quantum efficiency requires $\lambda_p \approx \lambda_{op}$. This can be achieved by the application of a reverse bias voltage, V_{det}, utilizing the QCSE. However, the reduction in α_{MQW} will reduce the gain in efficiency. As an alternative, T_{op} can be increased, which has no effect on α_{MQW}. This reduces the dependence on the QCSE

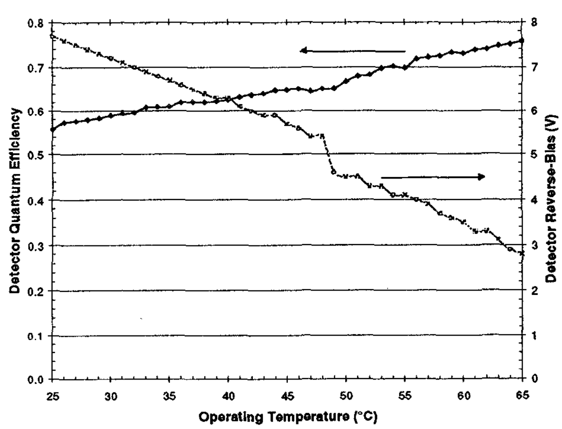

Figure 2 – Optimal $\eta_{detector}$ versus T_{op}

to achieve the required shift in λ_p, which increases efficiency. It is apparent that the detector will be more efficient at higher operating temperatures, provided that λ_o is not shifted past λ_{op}. Figure 2 plots the optimal detector efficiency (with the corresponding optimal V_{det}) versus T_{op}. The efficiency of the detector increases monotonically over the entire range of the temperature axis.

Systems using both QCSE Modulators and Detectors

For a QCSE modulator–detector combination, the overall figure of merit can be taken as the product of the individual figures of merit: [3]

$$\eta_{combined} = \eta_{modulator} \times \eta_{detector} \quad (2)$$

In combination, the parameters V_{pb} and V_{det} can be selected to optimize the combined efficiency for a given T_{op}, which is common to both devices. Based on the previous sections it is clear that, for modulators and detectors utilizing the same structure, the temperature ranges corresponding to highest efficiency for the modulator and detector will not be the same.

A plot of combined efficiency versus T_{op} is a point-wise multiplication of figures 1 and 2, and the general characteristics will be dominated by the modulator over the displayed temperature range. The optimal operating parameters for the system fall within the range:

T:	35 °C	to	45 °C
V_{pb}:	0.8 V	to	1.6 V
V_{det}:	5.7 V	to	6.8 V

Within the ranges specified above, the combined efficiency can be kept near 0.30.

IV. References

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