index variation of around 2% was observed for $P_{\parallel}$ at $V_R = 4$ V, on the other hand that for $P_{\perp}$ was smaller by a factor of three, i.e., around 0.7%. This polarisation dependence of index variation agree with the theoretical results for QWs,[9] thus proving the quantum wire effect of the present multi-layered QWs.

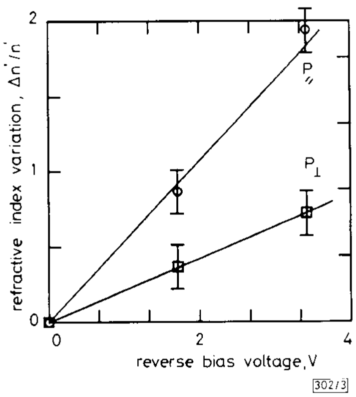

Fig. 3 *Applied voltage dependence of refractive index*
$\lambda = 1{\cdot}615\,\mu m$

Conclusion: We have fabricated three periods of GaInAs (9 nm)/InP (4 nm) multi-layered QW structure with the wire width of around 25 to 35 nm using a holographic lithography and a low defect ultra-high vacuum ECR-RIBE technique on OMVPE grown MQF wafer. The quantum effect in the wire direction was confirmed by PL shift. Large refractive index variation of 2% per quantum wire at $V_R = 4$ V and at wavelength of $1{\cdot}615\,\mu m$ and clear polarisation dependence theoretically predicted were observed for the first time.

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COHERENT OPTICAL RING USING COMMON LOCAL OSCILLATOR

Indexing terms: Optical communications, Oscillators

A coherent optical ring distribution system using a common local oscillator is investigated. The results show that equal IF signal for all the nodes can be easily achieved and there exists an optimum branch coupling ratio to achieve a maximum IF signal. In addition, equal IF signal to noise ratio is achievable when the signal and LO have limited output powers.

Introduction: The possibility of optical as well as electrical tuning provided by coherent schemes may be applied to optical local loops to distribute broadband signals.[1] For example, a coherent subcarrier multiplexed (SCM) system can be used to transmit tens of video channels to many subscribers.[2] At the receiving end of a heterodyne coherent system, a local oscillator (LO) cooperated with an automatic frequency control (AFC) circuit is employed to transpose information from the optical domain down to a microwave intermediate frequency (IF). For a system with N nodes, N pairs of LOs and AFCs are therefore needed. As the LO requires a costly DFB laser with narrow linewidth to reduce phase noise, the costs of LO and AFC will be very significant if N is large. In addition because the signal power decreases along the transmission path, the received signal power will be strongest at the first node and decreases for the succeeding nodes if the same branch coupler is used. This causes unequal signal for the nodes.

As an alternative, the ring structure may be adopted to deliver information from the centre to a number of users, for which we employ a high power and highly frequency-stabilised LO at the centre and distribute the LO signal along the transmission fibre to each node as shown in Fig. 1. Comparisons with a distribution system with individual LO several advantages can be drawn. First, $N - 1$ LO and AFC pairs are saved. Secondly, as only an LO is provided by the centre, it can be high frequency stabilised so that the IF frequency drift can be minimised. Thirdly, the LO can be implemented with very narrow linewidth laser so that the phase noise at the

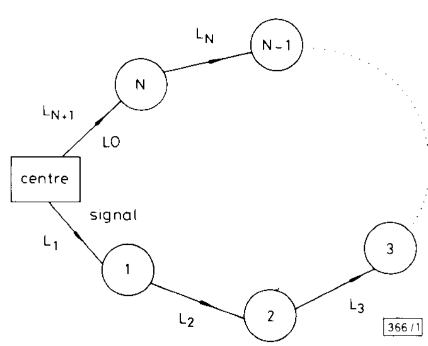

Fig. 1 *Coherent optical ring*

receiving end can be greatly reduced. Finally, as will be clearly seen later, an equal IF signal can be obtained for all the nodes, even for those where the received signal powers are unequal at each node.

Analysis: Consider a coherent optical ring with a centre and N nodes as shown in Fig. 1, where L_i denotes the fibre length between the $(i-1)$th and ith nodes. The LO signal propagates along the opposite direction of the message signal. A four port directional coupler is placed at each node to branch the signal and LO powers to the node. The directional coupler is modelled as Fig. 2 where $\beta < 1$ accounts for the coupler loss while x, $y < 1$ denotes the branching ratio for the signal and the LO, respectively.

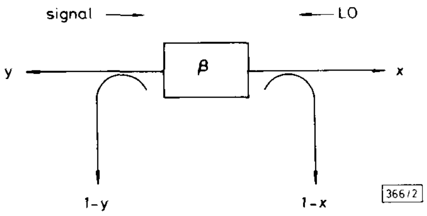

Fig. 2 *Four port directional coupler*

Let P_{s0} and P_{LO} be the transmitted signal and LO powers at the centre, and α be the fibre loss coefficient. The received signal for the rth node is given by

$$P_{sr} = P_{s0} \exp\left(-\alpha \sum_{i=1}^{r} L_i\right)(\beta x)^{r-1}[\beta(1-x)] \tag{1}$$

where the third term on the right hand side of eqn. 1 expresses the branch loss of the $r-1$ couplers ahead the rth node and the last term is caused by the rth coupler. Similarly, the received LO power at the rth node is written as

$$P_{Lr} = P_{LO} \exp\left(-\alpha \sum_{i=r+1}^{N+1} L_i\right)\beta^{N-r+1} y^{N-r}(1-y) \tag{2}$$

For a heterodyne receiver the square of the resulting IF signal current is proportional to the product of P_{sr} and P_{Lr} which can be formulated as

$$SIF_r = C_0 P_{sr} P_{Lr} = C_0 P_{s0} P_{LO} \exp\left(-\alpha \sum_{i=1}^{N+1} L_i\right) \times \beta^{N+1} x^{r-1}(1-x) y^{N-r}(1-y) \tag{3}$$

where C_0 is an appropriate constant. If we choose $x = y$, then

$$SIF_r = C_0 P_{s0} P_{LO} \exp\left(-\alpha \sum_{i=1}^{N+1} L_i\right)\beta^{N+1} x^{N-1}(1-x)^2 \tag{4}$$

which is apparently independent of r. Thus the IF signals for all the nodes are indeed the same if $x = y$. It is easy to see that the above result is obtained by the counter-propagation of the signal and LO such that the transmission and coupler losses for all the nodes are the same at the IF stage. There exists an optimum branching ratio x_{opt} which maximises SIF_r, given by

$$x_{opt} = \frac{N-1}{N+1} \tag{5}$$

Next, we consider noise. The variance of the noise current at the IF stage for the rth node can be written as

$$NIF_r = C_1(P_{sr} + P_{Lr}) + i_n^2 \tag{6}$$

where C_1 is an appropriate constant. The first term is the photodetector shot noise which is proportional to the incident optical power. The second term, i_n^2 accounts for the circuit noise, which is assumed to be the same for all the nodes. Here, laser phase noise is neglected. In general $P_{sr} + P_{Lr}$ is different for the nodes, hence the noise for each node is expected to be different, as the shot noise also differs.

Discussion and conclusion: We define the signal to noise ratio at the IF stage as

$$SNR_r = 10 \log \frac{SIF_r}{NIF_r} \tag{7}$$

For the particular case in which the centre has limited signal and LO powers so that i_n^2 dominates the noise term, it is apparent from eqns. 4 and 6 that SNR_r is nearly a constant and independent of r. Under such conditions, we can indeed obtain equal IF SNR for all the nodes. We further define the mean IF SNR as

$$\mu = \frac{1}{N} \sum_{i=1}^{N} SNR_i \tag{8}$$

and the standard deviation of the IF SNR as

$$STD = \sqrt{\left[\frac{1}{N} \sum_{i=1}^{N} (SNR_i - \mu)^2\right]} \tag{9}$$

The relation between μ and the number of channels N is shown in Fig. 3 which indicates the μ decreases about linearly with N and the decreasing rate increases with i_n^2. Therefore, the number of nodes should be limited to achieve an acceptable mean IF SNR. On the other hand, we see from Fig. 4 that the standard deviation of IF SNR increases as i_n^2 decreases. The IF signal is the same for all the nodes if $x = y$, while the shot noise at each node varies, as the received signal and LO powers are different. When i_n^2 is low, shot noise may dominate the noise terms so that SNR fluctuates, and in turn results in larger STD. For a large i_n^2, the effect of shot noise is

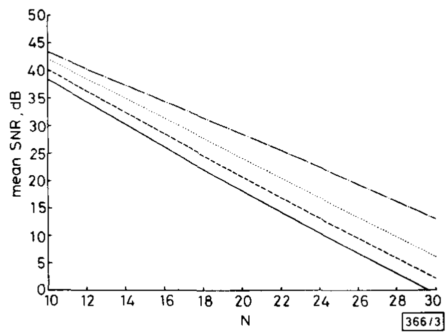

Fig. 3 *The relation between mean IF SNR and the number of channels*

$P_{s0} = P_{LO} = 1\,\text{mW}$, $C_0 = 0.5\,\text{A}^2/\text{W}^2$, $C_1 = 5 \times 10^{-11}\,\text{A}^2/\text{W}$, $x = y = N - 1/N + 1$; we assume $L_i = L$, $(i = 1, \ldots, N)$, and $\beta e^{-\alpha L} = 0.7$.
——— 100 nA; - - - - 70 nA; ······ 40 nA; -·-·- 10 nA

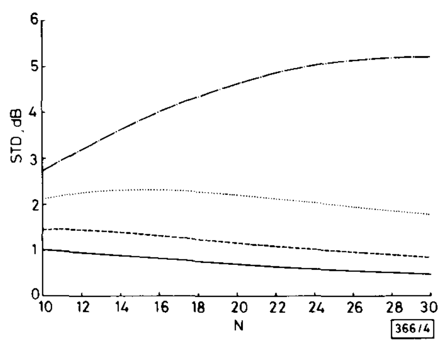

Fig. 4 *Relation between STD and the number of channels*

System parameters are the same as Fig. 3.
——— 100 nA; - - - - 70 nA; ······ 40 nA; -·-·- 10 nA

less significant so that SNR fluctuation is reduced. We also see that the STD is nearly unaffected by N when i_n^2 is large, but that it increases with N when i_n^2 is small. One can improve the mean IF SNR by increasing the LO power or reducing i_n^2. However, the standard deviation of IF SNR should stay at a reasonable level so that the worst case IF SNR is acceptable.

We have analysed a coherent optical distribution system with ring structure and a common LO. The LO is designed to propagate along a direction opposed to the signal, which is the key to achieving an equal IF signal. We see that in equal IF signal can be obtained by choosing the branching ratio, and in the particular case where the signal and local oscillator have limited output powers, we can indeed achieve equal IF signal to noise ratio for all the nodes.

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INTERCONNECTION-FREE SET LOGIC NETWORK BASED ON A BIO-DEVICE MODEL

Indexing terms: Logic and logic design, Bioelectrical phenomenon

A possible model of biomolecular switching devices based on enzyme-substrate reactions is proposed to construct an interconnection-free logic network. The algebraic properties are considered for the systematic synthesis of the network. To evaluate the response time of the biochip the effect of scaling down the device dimensions is discussed.

Introduction: Interconnection problems have been recognised to be a basic limitation in VLSI systems. Biomolecular computing systems may provide possibility of achieving the essential breakthrough for this difficulty.

The fundamental concepts of the interconnection-free logic operation proposed in this article are parallel distribution of logical information represented by varieties of molecules, and parallel selection using the specificity of enzymes. Enzymes, the biological catalysts, are highly specific in their choice of reactants called substrates. This unique selectivity can serve as an exact discrimination function for logic values, if these values are represented by varieties of substrates. Based on this idea, we present an interconnection-free logic network using biomolecular switching devices. A new set-theoretic switching algebra 'set logic system'[1] is introduced to describe the mapping between sets of molecules (logic values). It is shown that the set logic network can be constructed with simple bio-devices, and that it has highly parallel structure completely free of interconnections. Finally, the effect of scaling down the dimensions of the network is discussed in terms of substrate diffusion.

Bio-device model: Assume there exists a large number of enzymes, and let L be the set of their substrates. In the following discussion we assume that one kind of substrate represents one logic value and hence L is considered to be the set of all logic values.

A biomolecular switching device based on selectivity of enzymes is defined as

$$BO(X; D, Q) = \begin{cases} Q & \text{if } X \cap D = \phi \\ \phi & \text{otherwise} \end{cases} \qquad (1)$$

where $X, D, Q \subseteq L$, and ϕ denotes the empty set. The device is divided into two parts corresponding to the concepts of parallel selection and parallel distribution as shown in Fig. 1. An

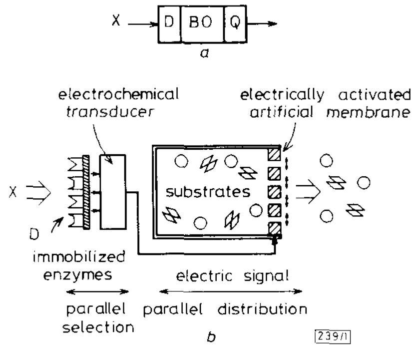

Fig. 1 *Biomolecular switching device*
a Symbol
b Operation

enzyme electrode composed of detector enzymes and electrochemical transducer controls the permeability of an artificial membrane. On the electrode the set of enzymes which correspond to the set of substrates D are immobilised. If input X contains at least one kind of substrate which belongs to D, the enzyme electrode detects this substance, and its electric signal inhibits the release of the substrates Q programmed in the device. Substrates are released if and only if $X \cap D = \phi$.

We can utilise electrochemical techniques[2,3] to realise the proposed bio-device.

Interconnection-free set logic system: A set logic function denoted by $F(X)$ is a mapping

$$F: 2^{L_\alpha} \rightarrow 2^{L_\beta} \qquad (2)$$

where $L_\alpha = \{\alpha_0, \ldots, \alpha_{p-1}\}(\subseteq L)$ is the set of input logic values and $L_\beta = \{\beta_0, \ldots, \beta_{q-1}\}(\subseteq L)$ is the set of output logic values. Set logic functions have the same capability as p-input q-output binary logic functions. A new unary operator called a set-theoretic literal is introduced

$$\overset{AB}{X} = \begin{cases} L & \text{if } A \subseteq X \subseteq B \\ \phi & \text{otherwise} \end{cases} \qquad (3)$$

where X is a variable on 2^L and $A, B \in 2^L$. Any set logic function $F(X)$ is represented using union, intersection and set-theoretic literal as

$$F(X) = \bigcup_{i=1}^{m} \left(P_i \cap \overset{A_i B_i}{X} \right) \qquad (4)$$

where $A_i, B_i \in 2^{L_\alpha}$, $P_i \in 2^{L_\beta}$. In order to realise the set logic function with simple devices, we introduce the redundant input logic values: $L_{\alpha'} = \{\alpha'_0, \ldots, \alpha'_{p-1}\}$ and the redundant output logic values: $L_{\beta'} = \{\beta'_0, \ldots, \beta'_{q-1}\}$, and define a new function $\mathbf{F}(\mathbf{X})$ using $F(X)$ as follows:

$$\mathbf{X} = X \cup f(L_\alpha - X) \quad \mathbf{F} = F \cup g(L_\beta - F) \qquad (5)$$

where $f: L_\alpha \rightarrow L_{\alpha'}$, $f(\alpha_k) = \alpha'_k (k = 0, \ldots, p-1)$ and $g: L_\beta \rightarrow L_{\beta'}$, $g(\beta_l) = \beta'_l (l = 0, \ldots, q-1)$. The function $\mathbf{F}(\mathbf{X})$ is generally expressed by simpler literals as

$$\mathbf{F}(\mathbf{X}) = \bigcup_{j=1}^{n} \left(Q_j \cap \overset{\phi C_j}{\mathbf{X}} \right) \qquad (6)$$