

polarisation controller within the fibre rings. The output intensity of the device can be changed in two ways. If the injection current is modulated by a 1 kHz triangular wave the frequency of the laser is modulated and an output as shown in Fig. 3 is produced. Alternatively, if the laser frequency is kept

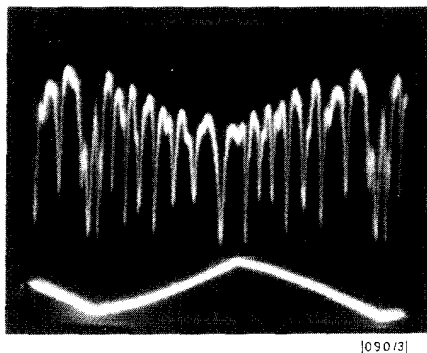


Fig. 3 Output intensity of device when laser injection current is modulated with triangular waveform at 1 kHz

Upper trace output of port 1; lower trace laser modulation
Loss and effective coupling coefficient identical to those of Fig. 2

constant the length of one of the fibre rings can be modulated in some way, for example by a PZ element, while the length of the other ring is kept constant. This allows one ring to be used for sensing while the other ring is used for reference. Fig. 4 shows the output intensity of the device when one of the fibre rings is modulated by a PZ element with a triangular wave at 6.3 kHz. The resolution frequency Δf was measured to be about 90 MHz and from eqn. 9 Δf was calculated as 92.5 MHz. The finesse of the device is approximately 6.

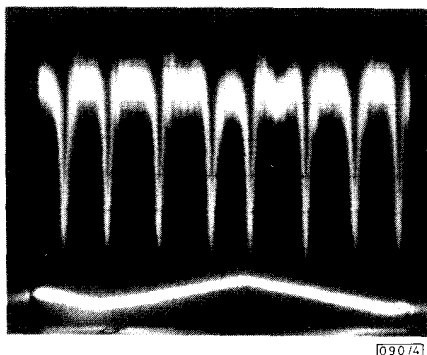


Fig. 4 Output intensity of device when phase of one ring is modulated by PZ element at 6.3 kHz

Upper trace output of port 1; lower trace modulating signal
Loss and effective coupling coefficient identical to those of Fig. 2

Summary: We have reported a device using two ring resonators and a single 3×3 fused coupler. One of the rings can be used as a reference arm and the other ring can be used as a sensing arm. Clearly the device has potential for use as a sensitive fibre optic sensor.

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MULTIPATH PROPAGATION MEASUREMENTS ON MANUFACTURING FLOORS AT 910 MHz

Indexing terms: Radiowave propagation, Radiocommunication

Measurements of propagation and time delay spread at 910 MHz on several different manufacturing floors are presented. The statistics of RMS multipath delay spread and the values of the distance/power law gradient are computed and compared for these experimental sites.

Introduction: Recently, indoor radio communications has attracted tremendous attention for applications in offices, manufacturing floors, warehouses, residential buildings, research laboratories, college campuses and hospitals.^{1,2} The development of a reliable statistical model of radio propagation into and within buildings is based on extensive measurements in many typical buildings. Measurements of multipath delay spread and distance/power law gradient for some residential buildings and research laboratories have been reported in References 3-5. This letter reports measurements made to characterise the multipath delay spread and to determine the distance/power law gradient of radio signals on several manufacturing floors, with different architecture and machinery.

Measurement set-up: Multipath propagation in indoor environments is either measured by spread-spectrum-type transmitter and receiver,³ or by the direct transmission of a narrow pulse and the subsequent observation of the received signal.^{4,6} In a manner similar to References 4 and 6, an RF oscillator on a mobile transmitter was used to generate a 910 MHz signal modulated by a train of 3 ns pulses with 500 ns repetition period. The stationary base equipment comprised the receiver coupled to a digital storage oscilloscope and a personal computer. Both the transmitter and the receiver used vertically polarised quarter-wave dipole antennas placed about 1.5 m above floor level. The transmitter was moved to various locations in the site, and the received multipath profiles were stored in the computer. The distance between the transmitter and the receiver varied between 1 and 50 m. A total of about 300 profiles were collected from measurements made in five areas on three different manufacturing floors.

Area A (Infnet Inc., N. Andover, MA) was a typical electronics shop floor having circuit board design equipment, soldering and chip mounting stations. Area B (also Infnet Inc.) included test equipment and storage areas for common electronic equipment, partitioned by metallic screens. Area C (Norton Co., Worcester, MA) had grinding machines, huge ovens, transformers and other heavy machinery. Area D (General Motors, Framingham, MA) was a car assembly line 'jungle' comprising all kinds of welding and body shop equipment. Area E (also General Motors) was a vast open area used for final inspection of the new cars coming out of the assembly line.

Experimental results: A typical multipath profile obtained from one of the locations is shown in Fig. 1. If the multiple paths or rays have gains β_k at delays τ_k , then the overall characteristics of these profiles are described⁴ by the multi-

path power gain

$$G \equiv \sum_k \beta_k^2 \quad (1)$$

and the RMS delay spread

$$\sigma_\tau \equiv \sqrt{[\overline{\tau^2} - (\overline{\tau})^2]} \quad (2)$$

where

$$\overline{\tau^n} \equiv \frac{\sum_k \tau_k^n \beta_k^2}{\sum_k \beta_k^2} \quad n = 1, 2 \quad (3)$$

These parameters were computed for each of the profiles obtained in various locations. Cumulative distributions of the multipath delay spread for the five areas are shown in Fig. 2.

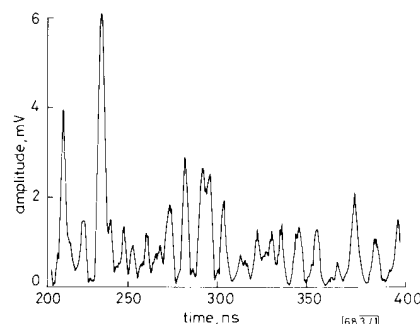


Fig. 1 Multipath profile obtained from location in area B

Area A, which had a lot of open space, had a median of 15.29 ns and a maximum delay spread of about 40 ns. Area B contributed to higher values of the median and the maximum delay spread. This was because most of the time the direct line-of-sight (LOS) was obstructed by some objects, resulting in a received signal composed of several reflections. Areas C and D had numerous machinery in a small area which resulted in higher values for the multipath delay spread. Area E had very few metallic structures, and thus a lower value of the multipath delay spread. The average value of the delay spread is dependent on the availability of a 'direct' LOS

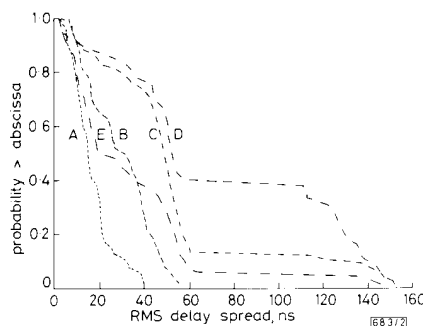


Fig. 2 Cumulative distributions of multipath delay spread for all areas
Medians: A: 15.29 ns, B: 31.62 ns, C: 48.90 ns, D: 52.57 ns, E: 19.37 ns

Table 1

Area	Numbers of locations	α	Max. RMS delay spread ns	Median RMS delay spread ns	Dynamic range of power fluctuations dB
A	54	2.348	40	15.29	30.34
B	48	3.329	60	31.62	39.85
C	75	2.185	152	48.90	35.50
D	45	2.196	150	52.57	28.02
E	66	1.398	146	19.37	24.97

between the transmitter and the receiver. For example, in Fig. 2, for the points to the left of the broken 'horizontal' lines, an unobstructed 'direct' path between the transmitter and the receiver was available. On the other hand, the LOS between the transmitter and the receiver was blocked by metallic objects for the points to the right of the broken 'horizontal' lines, leading to higher values of the RMS delay spread.

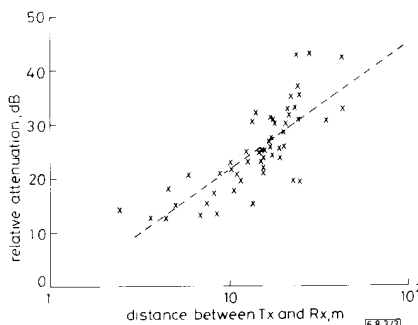


Fig. 3 Measured signal attenuation against distance
Area A, $\alpha = 2.348$; broken line is best-fit line

Fig. 3 shows the logarithmic plot of the measured attenuations (inverse of the multipath power gain) in area A, against the distance separating the transmitter from the receiver. These points, taken in dB, are fitted to a straight-line law of the form^{4,5}

$$L(r) = -\alpha \log r \quad (4)$$

where

$$L(r) = -10 \log_{10} [G(r)] \quad (5)$$

and r is the distance between the transmitter and receiver and α is the distance/power law gradient. Table 1 lists the values of α obtained for all the areas, together with the maximum and median values of the RMS delay spread and the dynamic range of power fluctuations. Areas A, C and D reported values of α between 2 and 3, and a dynamic range of power fluctuations between 28 and 36 dB. Area B, which included partitioning by metallic screens, contributed to a higher value of α and a maximum dynamic range of power fluctuations of about 40 dB. Area E, which was a vast open area, gave rise to an α less than the theoretical α for free space, and a minimum dynamic range of power fluctuations of about 25 dB.

Conclusions: Results of 910 MHz pulsed multipath propagation measurements on several manufacturing floors were presented. Areas which had a lot of machinery and less LOS between the transmitter and receiver gave rise to higher values of the RMS delay spread. Storage areas with partitioning by metallic screens resulted in higher values of α . On the other hand, open areas contributed to a value of α even less than that of free space. As compared to previous measurements made in residential areas and research laboratories,^{3,4} the values of the RMS multipath spread and the distance/power law gradient obtained on manufacturing floors are smaller. This is due to an easier availability of unobstructed 'direct' paths on manufacturing floors.

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KINETIC STUDY OF LIQUID PHASE EPITAXIAL GROWTH ON PROFILED SEMICONDUCTOR SUBSTRATES

Indexing terms: Semiconductor devices and materials, LPE, Epitaxy, Semiconductors

We present for the first time the semiquantitative analysis and computer simulation for LPE growth on profiled substrates. Our theoretical results are in agreement with the experimental data and can be used for improving the design and fabrication of heterojunction lasers and integrated optic devices.

Liquid phase epitaxial (LPE) growth on profiled semiconductor substrates has been developed¹ as one of the most successful techniques for fabricating mode stabilised heterojunction lasers. However, only a few qualitative explanations^{2,3} had been given up to now. In this letter, we proposed a model and perform for the first time the semiquantitative treatment and computer simulation for LPE processes on profiled substrates.

We start from the solute diffusion equation

$$\frac{\partial^2 C}{\partial x^2} + \frac{\partial^2 C}{\partial z^2} = \frac{1}{D} \frac{\partial C}{\partial t} \quad (1)$$

where C and D are, respectively, the concentration and diffusion coefficient of the solute. From a thermodynamic consideration,⁴ we have

$$\ln \frac{C^*}{C} = \Gamma_D K \quad (2)$$

where C^* and C denote the solute concentrations in the liquid solution in equilibrium with nonplanar (with curvature K) and planar portions of the substrate surface, respectively, and Γ_D is a thermodynamic factor. Hence, the boundary conditions for LPE growth on profiled substrates can be written as

$$C(x, z, 0) = C(T_1) \quad (3)$$

$$C(x, z_0, t) = \left(C(T_1) - \frac{R}{m} t \right) \exp(\Gamma_D K) \quad (4)$$

(for uniform cooling)

$$C(x, z_0, t) = C(T_2) \exp(\Gamma_D K) \quad (5)$$

(for step cooling)

where $z_0 = z_0(x, t)$ describes the solid-liquid interface during LPE growth, T_1 and T_2 are, respectively, the growth temperatures for the cases of uniform and step cooling, m is the slope of the liquidus curve at T_1 , and R is the cooling rate.

We first consider a substrate with channels of cosine shape cross section as follows

$$z_0(x, t) = \begin{cases} -\delta(t) \cos \omega x & |x| \leq \pi/2\omega \\ 0 & |x| > \pi/2\omega \end{cases} \quad (6)$$

where $\delta(t)$ denotes the depth of the cosine channel, $\omega = \pi/w$ is the space frequency, w is the width of channel. Since LPE growth is practically a slow process, we can write down the approximate solution for eqn. 1 as

$$C(x, z, t) = \begin{cases} C_p(z, t) - \delta(t) B \cos \omega x \exp(-\omega(z - z_0)) & |x| \leq \pi/2\omega \\ C_p(z, t) & |x| > \pi/2\omega \end{cases} \quad (7)$$

where $C_p(z, t)$ denotes the concentration for the case of planar substrate, and B is a factor determined by boundary conditions and expected to vary slowly with respect to time. According to balance of mass transferring at the solid/liquid interface, the thickness of LPE layer on profiled substrate can be obtained:

$$d(x, t) = \frac{1}{C^s} \int_0^t D \left(\frac{\partial C(x, z, t)}{\partial z} \right) \Big|_{\text{interface}} dt \quad (8)$$

Thus the time dependence of channel depth $\delta(t)$ can be expressed as

$$\delta(t) = \delta_0 \exp \left(\frac{-D\omega}{C^s} \left(C(T_1) \Gamma_D \omega^2 t + \frac{2Rt^{3/2}}{3m\sqrt{(\pi D)}} \right) \right) \quad (9)$$

(for uniform cooling)

$$\delta(t) = \delta_0 \exp \left(\frac{-D\omega}{C^s} \left(C(T_2) \Gamma_D \omega^2 t + \frac{2\Delta T t^{1/2}}{m\sqrt{(\pi D)}} \right) \right) \quad (10)$$

(for step cooling)

where $\delta_0 = \delta(0)$, C^s is the solute concentration in solid, ΔT is the amount of supercooling. Taking Fig. 1b of Reference 2 as an example, a flattened surface has been reached after growing the first layer and the growth time can be estimated to be about 80 s from the layer thickness on planar portion of the substrate. According to eqn. 10, the channel depth is only 0.02 μm after 80 s growth, which is in good agreement with the above experimental result although the channel profile is different from cosine shape.

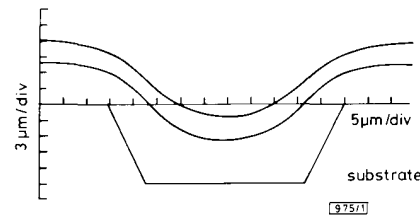


Fig. 1 Computer simulation for LPE growth shown in Fig. 2b of Reference 5