steps of 2 min separated by 1 min without silane and the sample cooled down to 200°C temperature. The whole epitaxial layer is almost defect-free in its bulk. The only remaining defects are some individual dislocations. In addition to the starting interface, interface layers are present between each successive step. These boundaries are less than 20 Å wide, but only the starting interface does show localised defects. The MIT group[2,3] analysed these interface defects and reported that one was amorphous and the other was crystalline in epitaxial relation with the substrate. It should be pointed out that at process temperatures above 800°C, these interface layers are not present in any step.

Electrical characterisation will be reported later.

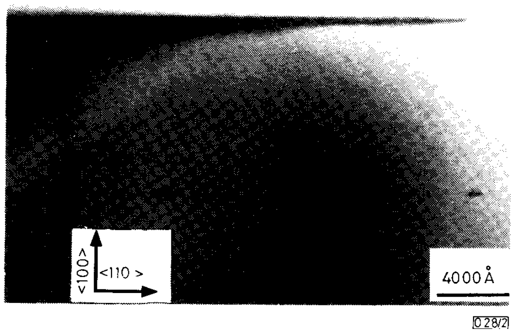

Fig. 2 *Cross-section TEM for successive epitaxial layers at 800°C*

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MULTIPLEXED FIBRE-OPTIC INTERFEROMETRIC SENSING SYSTEM: COMBINED FREQUENCY AND TIME DIVISION

Indexing terms: Semiconductor lasers, Remote sensing, Fibre optics, Multiplexing

It is shown that a frequency modulated laser diode source can be used to combine frequency division multiplexing and time domain addressing techniques to increase the number of interferometric sensors in a multiplexed fibre optic system. Demultiplexing is carried out in both the frequency and time domains to generate independent heterodyne carriers for different interferometers.

Introduction: There has been increasing interest in the multiplexing of optical fibre sensors to form passive sensing systems, located remotely from the active signal processing. Three different methods have been described previously: coherence, frequency division and time division multiplexing.[1–5] The coherence multiplexed system is based upon using a source with a short coherence length relative to the sensing interferometers' path imbalances. By balancing the path differences of the sensing interferometers by using corresponding receiving interferometers the phase information can be recovered.[1,2] The frequency division technique has been applied to a system containing several unbalanced interferometers where the path differences are unequal. The frequency of the laser source is controlled so as to modulate the phase of each interferometer by an amplitude which is an integral number of 2π rad. The phase information is then recovered by bandpass filtering the multiplexed output at different frequencies for different interferometers.[3] Time division multiplexing has been described using a pulsed source for unbalanced interferometers[4] and also in conjunction with coherence multiplexing.[5]

Recently a time division technique has been demonstrated where the frequency of a laser source is modulated with a gated ramp.[6] This approach provides a pseudoheterodyne output for each sensor.[7] In this letter we again use the same time domain addressing technique but in conjunction with a frequency division technique to extend the number of sensors in a multiplexed system.

Experiments: Fig. 1 shows schematically the multiplexed array, where each element S_1, S_2, …, corresponds to a sub-

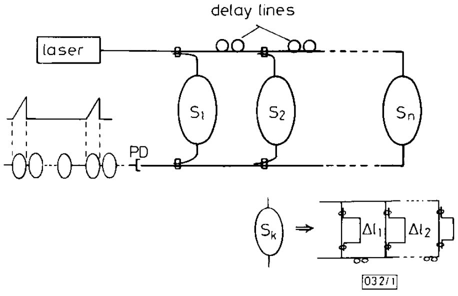

Fig. 1 *Schematic diagram for an extended multiplexed sensing system when laser injection current is modulated with a gated ramp*

S_1, S_2, …, S_n are subsystems of interferometers; PD = photodiode. Each oval symbol represent output of a subsystem

system. Each subsystem comprises a number of interferometers having different path length imbalances, so that they can be frequency division multiplexed.[3] Each subsystem is separated from its neighbour by an optical delay line, so that the subsystems may be time multiplexed.[4–6] The array is illuminated by a laser diode continuously biased above threshold, but with pulsed modulation, where each pulse is a saw-tooth ramp current. The duration of the pulse is less than the time delay between neighbouring subsystems, and the time between pulses is greater than the maximum time delay in the array.

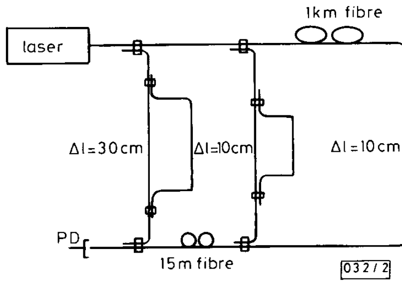

Fig. 2 *Experimental set-up when two subsystems containing two Mach–Zehnder interferometers (Δl = 30 cm and Δl = 10 cm) and one interferometer (Δl = 10 cm) are used*

The returning detected pulses are therefore distinct for each subsystem. Because the individual interferometers within each subsystem are unbalanced, the ramped laser frequency produces a pseudoheterodyne carrier during the pulse.[7] The frequency of the carrier is dependent on the path imbalance so that, provided the path lengths are properly chosen,[3] each interferometer within a particular subsystem can be distinguished by its corresponding carrier frequency.

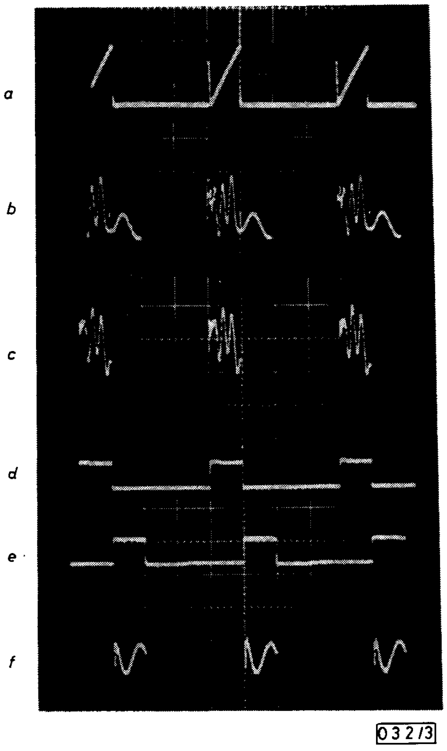

Fig. 3 *Signals in time domain*

a Laser injection current
b Photodiode output
c Output of first subsystem after *b* is gated
d, *e* Gating signals for demultiplexing output of two subsystems
f Gated photodiode output corresponding to second subsystem
x-axis: 5 μs/div

The experimental set-up to test this concept is shown in Fig. 2 where two subsystems of sensors were used, one containing two Mach–Zehnder interferometers with path imbalances of 10 and 30 cm and the other containing one interferometer with a path imbalance of 10 cm. A 1 km fibre delay line was deployed to produce a delay time of 5 μs between these two subsystems. A delay line of 15 m (longer than the coherence length of the source) separated the two interferometers inside the first subsystem is a combination of two interferometric current was modulated with a gated saw-tooth waveform (Fig. 3*a*) with a ramping time of 5 μs. The amplitude of the laser modulating current was adjusted such that the interferometers with path imbalances of 10 cm were driven over one period of their transfer function (equivalent to a phase modulation of 2π rad). Hence the interferometer with a path difference of 30 cm was driven over three cycles of its transfer function. The photodiode output is shown in Fig. 3*b* where the output of the delayed interferometer has a delay of 5 μs compared with the output from the first subsystem which in our experiments is nearly simultaneous with the ramp signal. The output from the first sub-system is a combination of two interferometric outputs. The photodiode output signal was demultiplexed in the time domain to separate the outputs from the two different subsystems (Fig. 3). By bandpass filtering the gated outputs at the required frequencies the separate phase carrier outputs of each interferometer within a subsystem can be simultaneously generated. For our experiments the output of the first subsystem (containing two Mach–Zehnders) should be simultaneously bandpass filtered at frequencies of 200 kHz and 600 kHz.

The crosstalk between the interferometric outputs of a subsystem is as discussed by Sakai[3] for frequency division multiplexed systems. Between the subsystems the crosstalk is dependent on the time delay and the synchronisation in the demultiplexing.[6]

We have described a technique to combine the time domain addressing technique with frequency division multiplexing to extend the number of fibre optic interferometric sensors in a multiplexed system. We have demonstrated the practicality of this technique in the case of three sensors deployed as two subsystems. This approach to multiplexing is also applicable when the source is modulated with a gated sinusoidal current to produce carriers at higher frequencies.[8]

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