epitaxy apparatus. On the semi-insulating substrate, an undoped N^--type layer (0·1 μm, $N_d \simeq 2 \times 10^{15}\,cm^{-3}$), an N-type layer (0·2 μm, $N_d = 10^{17}\,cm^{-3}$) and a P-type layer (0·3 μm, $N_a = 2 \times 10^{18}\,cm^{-3}$) were deposited successively. Silicon was used as the donor and beryllium as the acceptor for doping.

Using optical photolithography and liftoff techniques, the gate metallisation (AuZn, 0·2 μm thick) was evaporated and used as a mask for the etching of the gate. After etching, gate contacts were alloyed at 420°C for 10 s. Then etching of the mesa isolation was performed with an Si_3N_4 mask; the fabrication concludes with the deposition of source and drain contacts (AuGe, 0·2 μm thick) which are self-aligned with respect to the gate metal.

All etches were performed in a commercial planar diode RIE system (Alcatel GIR 100) operating at a frequency of 13·56 MHz, as described in Reference 3. The substrate was deposited on to a silica base plate which covered a stainless steel platen of the cathode; this electrode was water-cooled, thus avoiding any degradation of photoresists or metallisations used as masks. As etching of the gate requires precise control of the depth, we calibrated the etching rate for GaInAs as a function of RF power density, composition of the gas mixture and total pressure in the reactor. With the experimental condition given in Fig. 2, we obtained abrupt,

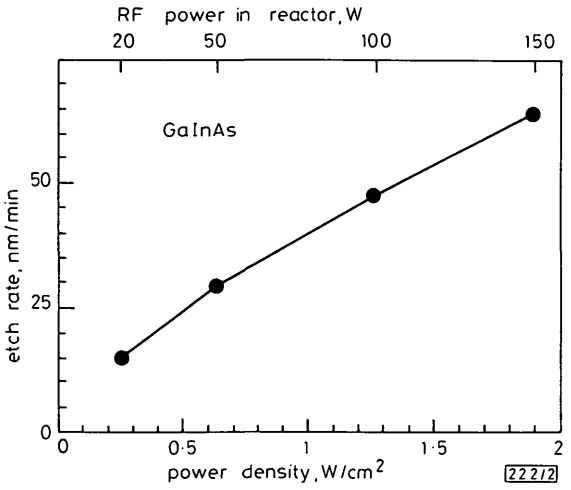


Fig. 2 *Etch rate dependence on power density*

residue-free sidewalls and smooth surfaces with etching rates varying from 15 to 65 nm/min. For RF power densities of less than 0·25 W/cm^2 it was not possible to control in a reproducible way the ignition of the plasma discharge, while for RF powers higher than 1·8 W/cm^2 the surface of the etched material became rough. To ensure that all the P-type GaInAs layer is removed, we chose to etch to a depth of 0·32 μm. Two runs of wafers were etched: the first at a power of 0·63 W/cm^2 for 12 min and 50 s, and the second at 1·27 W/cm^2 for 7 min and 40 s. With both of these etching conditions we obtained similar electrical results with excellent uniformity on all wafers. Fig. 3 shows a photograph of a complete device, while Fig. 4 shows typical $I(V)$ characteristics of a device where the source-drain spacing is 5 μm, and the gate is 1 μm long by

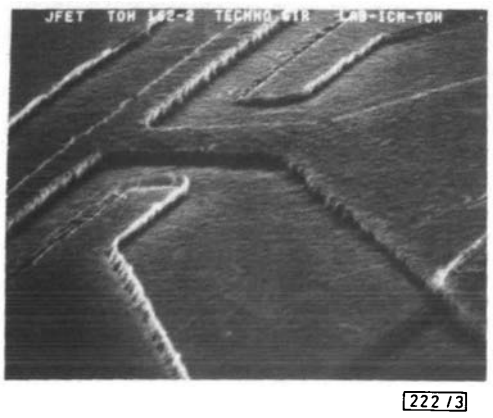


Fig. 3 *Scanning electron micrograph of a GaInAs junction FET*

300 μm wide. Good saturation behaviour is obtained together with a transconductance of 87 mS/mm, which is comparable to values previously measured on similar structures.[4,5] The

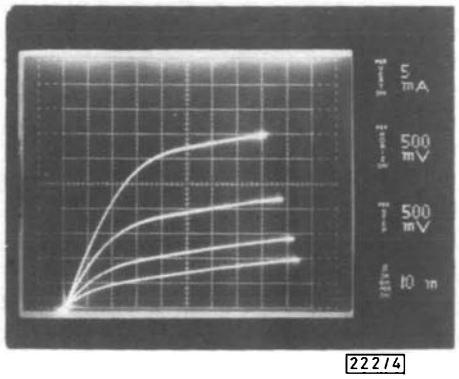


Fig. 4 *Typical $I(V)$ characteristics of junction FET*
Gate is 1 μm long by 300 μm wide

absence of hysteresis in the $I(V)$ characteristics is indicative of the low concentration of electrically active defects both in the channel or at the surface of the access region of the FET. This suggests that if electrical defects are induced on the surface during the etching process, their density is very low or can be annealed during the short alloying heat treatment.

In conclusion, we have successfully applied the metal organic reactive ion etching technique to the fabrication of a GaInAs junction FET. This technique permits good control of the etching depth with low surface damage.

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PASSIVE OPTICAL LOCAL NETWORKS FOR TELEPHONY APPLICATIONS AND BEYOND

Indexing terms: Optical communications, Telephony, Networks, Optical transmission

A new digital telephone system is described using a passive optical network. Downstream transmission is broadcast and optical time-division, multiple-access (OTDMA) is used in the upstream path. The principle advantage of this approach is that exchange resources and fibres are shared between a large number of customers.

Introduction: Following earlier BTRL work[1–3] aimed at exploring prospects for entirely passive all-optical architectures for new broadband services, we report here on a passive

optical architecture to meet the needs of telephony/narrowband customers. This passive architecture avoids the need for remotely stationed electronics in the field which can give rise to maintenance and power feed problems. Additional advantages include reduced amounts of installed fibre, low fibre count cables and the sharing of optoelectronic devices. Initial cost studies indicate that the approach could be economic for 2–4 line business customers, with prospects also for the residential sector. The network, installed initially for narrowband purposes, can be progressively enhanced by WDM to provide a wide range of new services, ranging from additional narrowband to the broadband ISDN and HDTV.

Basic network concept: Fig. 1 illustrates the TPON (telephony on passive optical network) system. A single fibre is fed from the exchange and fanned out via passive optical splitters at the

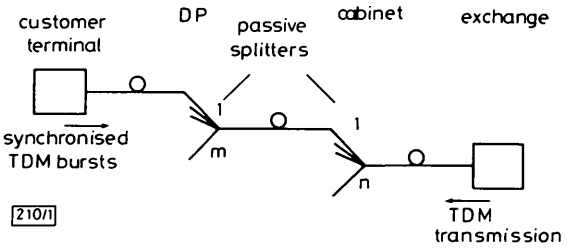


Fig. 1 *Basic TPON network*
Single-mode fibre throughout

cabinet and distribution point (DP) positions to feed a number of individual customers. Each customer receives a fibre from a DP and, via this, a TDM signal broadcast from the exchange. The customer's equipment accesses the particular time slots of the TDM intended for that destination plus any associated signalling channels. Further interface circuitry provides the detailed services required by the customer, for example, analogue telephony or ISDN services. Customers transmit digital speech or data back to the exchange using OTDMA in a low-duty-cycle mode with the converging traffic streams passively interleaving at the DP and Cabinet branching points. Correct timing is achieved by synchronising the customers' equipment to the exchange clock and using a ranging protocol to set a digital delay line in the customers' equipment to access vacant time slots at the exchange receiver.

Two additional amplitude thresholds are provided at the exchange receiver, which allow monitoring and control of the received amplitude. Each customer's time slot is sampled sequentially and the transmitter power is adjusted via a downstream telemetry path so that the received signal falls between the two thresholds. One of the advantages of this approach is that it is not necessary to provide a monitor photodiode at each remote transmitter.

The cost of the customer's transmitter may be further reduced because it operates in a low-duty-cycle mode. By operating in this mode there is no need for temperature control of the source. The duty cycle depends on how many time slots are being accessed, and for a single-line customer this may be as low as 1 : 128.

Provisional system design views favour an optical split of up to 128 ways and a transmission rate of 20 Mbit/s. This allows an attractive set of service options for both business and residential customers. Sufficient capacity is available to feed up to 120 customers (allowing eight spare test ports) with a 144 kbit/s ISDN connection. Business customers requiring larger capacities would access multiple time slots as required up to the maximum capacity of the system.

Since downstream traffic is broadcast, the system design requires measures to ensure communications security. Casual access to time slots is prevented by the design of the customers' equipment. Time slots are accessed according to the setting of the digital delay line in the customers' equipment. This function is remotely controlled by the exchange. Encryption and time slot hopping are other measures which may be considered necessary.

Early experimental systems: The network concepts proposed for TPON have been partially demonstrated in the laboratory at lower transmission rates via two early experimental systems based on available hardware. The purpose of the first was to demonstrate broadcast telephony in the downstream direction and synchronous optical TDM in the return direction. The same wavelength was used in both directions and the power divider loss was equivalent to that of a 128-way split. In addition, the second experiment demonstrated automatic ranging and signalling, a number of external plant features and the ability to use a TDMA packetised frame structure in the return direction of transmission.

(*a*) *First experimental system:* Fig. 2 shows the general configuration which uses proprietary primary multiplexers (PMUXs) in the exchange and customer's terminals. In the downstream direction, 30 PCM channels were multiplexed to 2·048 Mbit/s HDB3. This signal directly modulated a 1·3 nm IRW semiconductor laser. The signal then passed through a fused taper coupler to separate the transmit and receive paths at the exchange and then through 6 km of single-mode fibre representing the link to the cabinet. It was then distributed to the individual customers via a multiple-stage optical power divider equivalent to a 128-way splitter. This was fabricated from wavelength-flattened fused biconical taper couplers and had an insertion loss of 25 dB. Each output from this splitter was connected to a further fibre length and coupler to separate the receive and transmit paths at the customer's end. Commercial PINFET transimpedance receivers with a quoted minimum sensitivity of −52 dBm were used.

In the upstream direction, serial bytes were interleaved to form a synchronous 2·048 Mbit/s frame which could be received by the exchange PMUX. NRZ binary speech samples in serial byte format were picked directly off the customers' PMUX backplane by the transmitter card. This card included a laser as before and a programmable digital delay line to shift the customer's channel into its allocated time slot. Output from the customer's laser then passed back through the system to the exchange receiver. The binary multiplex was then converted into HDB3 format, using a digital line terminating unit which also provided the frame synchronisation word for the exchange.

(*b*) *Second experimental system:* Fig. 3 shows the general configuration, which was based on an adaptation of a multipoint radio system[4] operating over a passive single-mode fibre network installed by the blown fibre technique. As before, the network incorporates optical splitters at flexibility points for duplexing and distribution. The radio transmission shelf in the central station was replaced by a laser transmitter and optical receiver. Similarly, the subscribers equipment was modified by the addition of an optoelectronic interface. One line of a pilot ISDN exchange simulator was connected to a TPON cus-

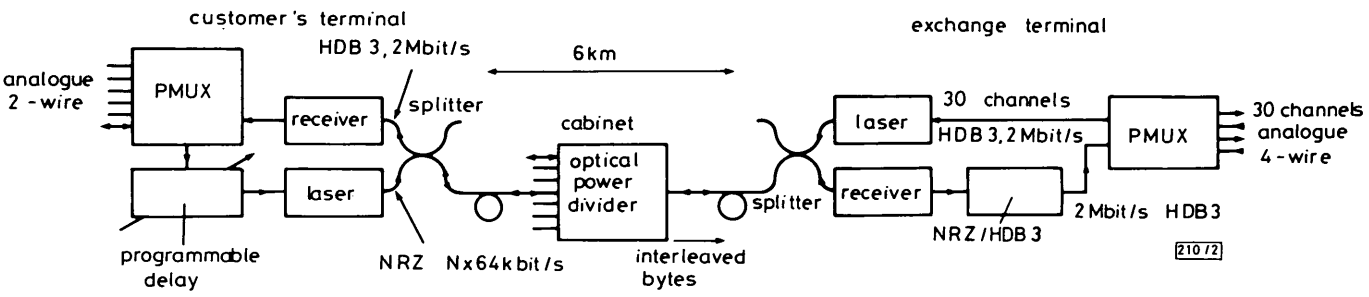


Fig. 2 *TPON first experimental system, using primary multiplexers (PMUXs)*

tomer. Digital speech was transmitted in both directions simultaneously by calling between a second ISDN line and the TPON subscriber. Wavelength-flattened 2 × 2 splitters were mounted in terminal boxes at each end of the network to provide full duplex transmission capability. A 4 × 4 flattened array was mounted in an external cabinet to model a street flexibility point.

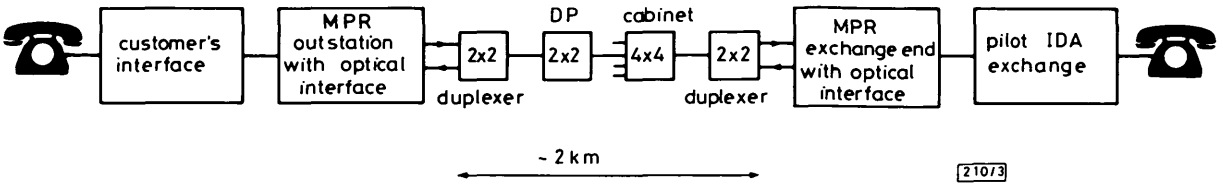


Fig. 3 *TPON second experimental system, using multipoint radio (MPR)*

The transmitter launch power was −8·5 dBm at 1·3 nm. A 2 Mbit/s optical modem with a receiver sensitivity of −30 dBm provided the receiver stage. In the upstream direction, transmission is by TDMA, with each outstation sending bursts of data in assigned time slots. In this case DC-coupled optical transmitters and receivers were used to avoid baseline drift in the absence of received data during the quiet period between bursts. Each customer transmitter was turned fully off when no data were being sent, to avoid interchannel interference on the shared fibre. A ranging function was provided to correctly interleave the bursts to form a TDMA stream.

Conclusion: This letter has described the technical basis for a passive optical network to meet the needs of telephony customers in a potentially economic fashion. Two systems experiments have demonstrated in a preliminary way the basic passive TDMA approach, ranging, wavelength-flattened optical plant and bidirectional operation. Both systems, however, utilised equipment designed for other applications, and a more advanced demonstrator is now under construction which simultaneously addresses all system requirements, including network security.

The passive optical architecture described offers considerable opportunity for evolution towards the broadband multiservice network of the future via the addition of separate optical wavelengths carrying the new services onto the same passive optical network.[2] In the longer term, large numbers of optical wavelengths will become available, leading to almost unlimited opportunities for the introduction of new services.

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GaInAsP BURIED CHANNEL EA MODULATOR FOR 1·3 μm FIBRE LINKS

Indexing terms: Integrated optics, Optical modulation, Electro-optics, Optical waveguide components

Double-heterostructure (DH) GaInAsP/InP buried channel waveguide electroabsorption (EA) modulators are demonstrated. They are designed for external intensity modulation of 1·3 μm laser light and direct coupling to single-mode fibre. For a 650 μm-long device, a 30 dB on/off ratio has been achieved at a bias voltage of −9 V. The substrate light is found to be a limiting factor of the measured extinction ratio for short modulators, but not for long (1·8 mm) modulators.

There is presently strong interest in external modulation of laser light. This is due to the fact that direct modulation of laser diodes has been shown to cause frequency chirping of the modulated signal,[1] while chirping in external modulators is expected to be small.[2] As a consequence, both phase and amplitude modulator designs are being studied.[3–13] For applications in long-haul, high-data-rate fibre communication at the 1·3 and 1·5 μm transmission wavelengths, III-V compound semiconductor waveguide modulators using the electroabsorption (EA) effect are particularly attractive due to their potential for monolithic integration,[10,11] high extinction ratio,[6,7] high modulation rate[12,13] and low driving voltage.[6] So far, semiconductor channel waveguide modulators have only been investigated using the ridged waveguide structure,[6–8] and buried double-heterostructres using LPE regrowth.[9] In this letter we report on the performance characteristics of a GaInAsP/InP DH buried channel waveguide electroabsorption modulator. This device is fabricated with single-step liquid-phase epitaxy (LPE) and a zinc diffusion process. The device structure and waveguide dimensions are designed specially for coupling to single-mode fibre.

The waveguide structure, shown schematically in Fig. 1, has an active region of 6 × 3 μm². The device fabrication is as follows. Prior to LPE, an undoped InP substrate is etched to form groove channels (6 μm wide, 4 μm deep) along the (100) direction with HCl using Si_3N_4 as the etching mask. Three layers, an InP layer, a quaternary layer (with bandgap energy E_g corresponding to 1·25 μm) and an InP cladding layer, are grown over the channelled substrate. These layers are undoped and have a background electron concentration of

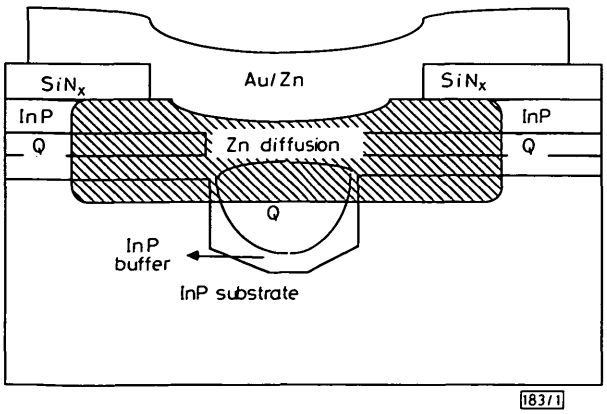


Fig. 1 *Schematic cross-section for buried channel waveguide modulator*