Experiment: Mode-locked and Q-switched pulses from a Nd-YAG laser operating at $1{\cdot}319\,\mu m$ were passed through an $LiIO_3$ crystal to generate the seed second-harmonic at 659 nm. Both $1{\cdot}319\,\mu m$ and 659 nm of peak powers 520 W and 0·3 W respectively were coherently launched into the silica fibre, which was codoped with Ge and P_2O_5 and had a single-mode cutoff of 850 nm. After 3 hours the $LiIO_3$ crystal was removed and it was observed that the SH power generated in the fibre had grown from an initial $2\,\mu W$ to 25 mW peak power (Fig. 1). The active length of the fibre was 13 cm, as determined by cutting back the fibre.

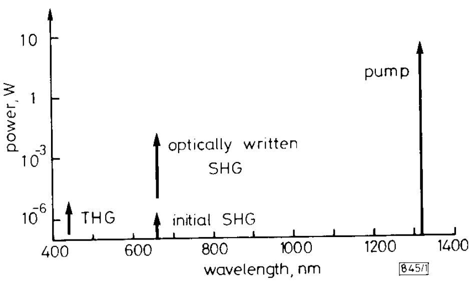

Fig. 1 *Harmonic generation in an optical fibre pumped at $1{\cdot}319\,\mu m$*

Mixing between the pump $1{\cdot}319\,\mu m$ and the seed 659 nm waves via the third-order nonlinearity in the fibre generates a DC electric field.[3] The field is periodic in space with a period given by the phase mismatch vector between the pump and the probe. The period was calculated as $64\,\mu m$ in this fibre. Defects are aligned in the DC field to give a permanent $\chi^{(2)}$ grating. The periodic $\chi^{(2)}$ grating generates a phase-matched second harmonic at 659 nm when pumped at $1{\cdot}319\,\mu m$.

Defects can be created in a fibre with wavelengths below 550 nm but 659 nm does not produce significant defect centres. However it was observed that a peak power of approximately $10\,\mu W$ of third harmonic at 439 nm is also generated in the fibre.

The third harmonic power is given by

$$P_{3\omega} = \frac{4P_\omega \omega^2 \chi^{(3)2} l^2}{c^4 \varepsilon^2 A^2} \tag{1}$$

where l is the interaction length for THG, ω is the pump frequency, A is the fibre spot area, and $\chi^{(3)}$ is the third-order susceptibility (10^{-22}).

The third harmonic generation is not phase-matched and therefore only builds up over the coherence length of $15\,\mu m$. We calculated the peak third harmonic power as $27\,\mu W \pm 20\%$ which is in good agreement with the measured values.

Defect creation in phosphorus doped fibres is highly sensitive at this wavelength.[4] It is therefore thought that short wavelength light produced by THG in optical fibres is responsible for the creation of defects which are then aligned by the DC field to produce a net dipole moment and hence a $\chi^{(2)}$ in the fibre.

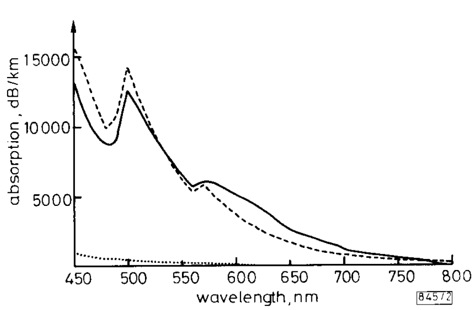

Fig. 2 *Increase in optical absorption during writing process or by excitation by 457 nm light*

- - - - fibre with $1{\cdot}319\,\mu m$ pumped SHG grating
——— fibre irradiated with 457 nm
······· non-irradiated fibre

Further evidence for the creation of defect centres by third harmonic generation is given by the increase in the fibre loss at wavelengths below 600 nm (Fig. 2). A similar fibre was exposed to an equivalent average energy at 632 nm. No change in the absorption was observed as a result of this irradiation. However, exposing the same fibre to 457 nm light induced an absorption identical to that of the grating. These induced absorptions are typical of those obtained by UV or gamma ray excited defects in fibres.

The conversion efficiency at $1{\cdot}319\,\mu m$ is weak compared with reported 5% conversion at $1{\cdot}064\,\mu m$. This is partly due to the weak seed light of 0·3 W and also the smaller third-order nonlinearity at this wavelength, resulting in a DC field during the writing process of the order of 10 V/m.

Conclusions: We have demonstrated for the first time second harmonic conversion from $1{\cdot}319\,\mu m$ to the red $0{\cdot}659\,\mu m$. The optically written defect centres are not easily excited by these wavelengths. However, there is significant third harmonic generation at 439 nm, which is shown to have sufficient energy to excite defect centres in the P_2O_5-Ge doped silica fibre. A considerable improvement in conversion efficiency may be expected with higher seed intensities.

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GaInAs/GaAs STRAINED LAYER MQW ELECTROABSORPTION OPTICAL MODULATOR AND SELF-ELECTRO-OPTIC EFFECT DEVICE

Indexing terms: Semiconductor devices and materials, Optical modulation, Electro-optics

We observed a clear excitonic absorption effect at room temperature in MBE-grown $Ga_{1-x}In_xAs$/GaAs strained layer multiple quantum well structures, and fabricated optical *pin* modulators on the same structures. A change of 27% in the transmission, corresponding to a change in the absorption coefficient of $2260\,cm^{-1}$, with 6 V reverse bias voltage and at 9710 Å wavelength, was measured. We also operated the modulator as a self-electro-optic effect device, resulting in a nonlinear optical input/output characteristic.

Introduction: Multiple quantum well (MQW) *pin* modulators, based on the quantum-confined Stark effect, have been demonstrated extensively in the AlGaAs/GaAs material system.[1,2] The ternary material GaInAs, however, is becoming increasingly interesting for optical modulator and laser applications in integrated optics because it allows operation in the infra-red region. High-frequency MQW electroabsorption optical modulators have been reported in the GaInAs/InP material system, grown by MOCVD,[3] and in the GaInAs/AlInAs material system grown by MBE.[4] In this letter we report an MBE-grown *pin* electroabsorption light modulator in the strained layer GaInAs/GaAs[5] material system. We first describe the modulator structure and the device fabrication. Then we discuss the electroabsorption effect, which is the basis for the modulator operation, along with the device performance. Finally, we describe the performance as a self-electro-optic effect device (SEED).[6]

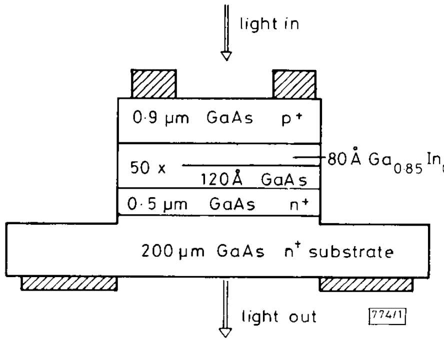

Fig. 1 *Schematic diagram of optical modulator*

Structure and fabrication: A schematic diagram of the device structure investigated is shown in Fig. 1. The samples were grown on an *n*-GaAs substrate (Si-doped at $3 \times 10^{18} cm^{-3}$) by MBE. First we grew a 0·5 μm *n*-GaAs buffer layer (Si-doped at $3 \times 10^{18} cm^{-3}$) followed by 50 periods of $Ga_{0.85}In_{0.15}As$ quantum wells of 80 Å thickness with 120 Å GaAs barriers (undoped). This was followed by a 0·9 μm *p*-GaAs cap layer (Be-doped at $3 \times 10^{18} cm^{-3}$). Large (1 mm^2) mesa devices were fabricated using AuBe rings as contact on the *p*-material and an AuGe/Ni/Au contact on the *n*-substrate.

Electroabsorption effect and modulator performance: Transmission measurements while applying different voltages across the *pin* structure reveal that a strong electroabsorption effect occurs. A broadband low-power (20 W) tungsten lamp was used as the light source. The light beam was focused on the aperture (600 μm diameter) of the AuBe ring. The light, transmitted from the backside of the device, was focused on the entrance slit of a SPEX 1·26 m focal length grating spectrometer, using two objective lenses. The dispersed light was detected by a liquid-nitrogen-cooled Ge photodetector. Typical room-temperature transmission curves for the described device are shown in Fig. 2. With increasing reverse bias voltage across the *pin* diode, the transmission spectrum changes progressively. A shift of the excitonic resonance (indicated by an arrow), which is identified as the first heavy hole excitonic transition, can be seen when the voltage is increased. This behaviour is called the quantum-confined Stark effect.[2,7] A broadening of the absorption features is also observable. These results agree with previous experiments.[2,5]

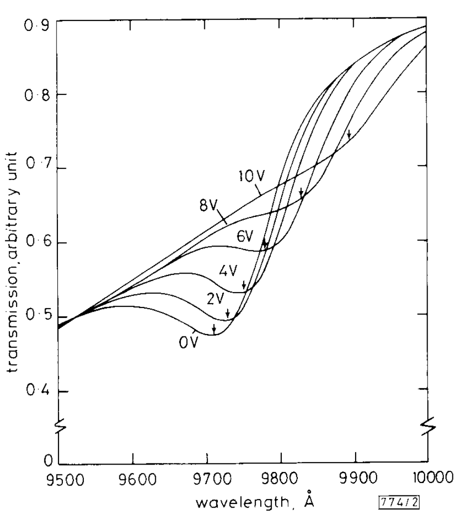

Fig. 2 *Transmission spectra at different reverse bias voltages*

The use of a *pin* doping scheme in this device allows the application of moderately large electric fields perpendicular to the layers with low voltages. The modulation response with 6 V reverse bias voltage in terms of the change in absorption coefficient is shown in Fig. 3. The absorption coefficient is calculated from the transmission spectrum, taking into account the reflection at the GaAs surface.[6] Depending on the wavelength, positive or negative changes of the absorption coefficient can be realised. With respect to the 0 V spectrum, a positive change occurs at the absorption edge, while a negative change occurs at the peak of maximal absorption. With 6 V applied voltage a maximal decrease of $-2260 cm^{-1}$ at 9710 Å and a maximal increase of $1360 cm^{-1}$ at 9820 Å were observed. The output intensity of the modulator increased by 27% at 9710 Å as the voltage was swept from 0 to 6 V. At 9820 Å a 16% decrease of the output light was measured. The high-speed performance of this type of modulator has proven to be very good.[1,3] The bandwidth mainly depends on the *RC* time constant of the structure. Bandwidths of 1 GHz and larger should be possible using scaled devices with a minimal parasitic capacitance.

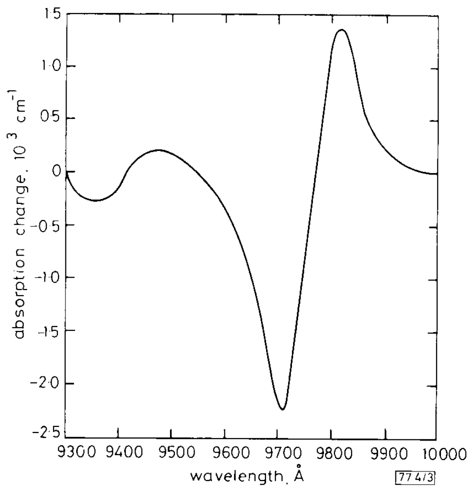

Fig. 3 *Modulation response for a voltage sweep from 0 to 6 V*

Self-electro-optic effect device: We also operated the same *pin* structure as a SEED in an external circuit with a series resistor of 1 MΩ and a reverse bias voltage source. In the SEED configuration the device operates simultaneously as a modulator and a photodetector. The optical input/output characteristic of the SEED was measured at the 0 V exciton peak (9710 Å). A monochromatic probe beam of approximately 20 μW was focused on the aperture of the Au–Be ring. We used a 100 W tungsten-halogen lamp with a model 270 McPherson monochromator to generate the probe light. The light transmitted from the backside of the device was measured in the same manner as for the electroabsorption experiment. We applied just enough reverse bias (10 V) to change

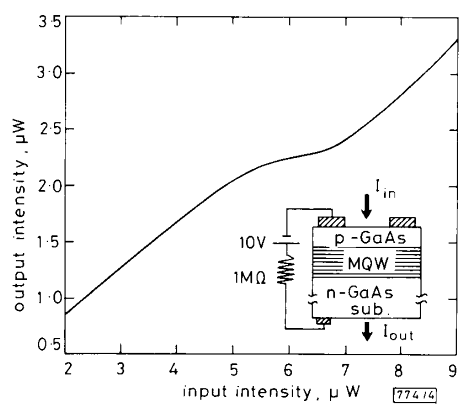

Fig. 4 *Optical input/output characteristic of SEED*

the absorption spectrum such that there is little absorption at 9710 Å. As the beam intensity increases it generates a photocurrent that induces a voltage drop over the resistor. The voltage over the device decreases and the absorption increases. This mechanism results in a nonlinearity in the optical input/output characteristic as shown in Fig. 4.

Conclusions: GaInAs/GaAs MQW structures show excitonic absorption peaks at room temperature. Significant changes of the absorption spectrum near the exciton peaks with applied electric field can be used to make optical *pin* modulators and self-electro-optic effect devices that operate in the infra-red light region.

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AUTOMATIC HYSTERESIS LOOP MEASUREMENTS DURING HEAVY-ION IRRADIATION OF FERROMAGNETIC METALLIC GLASSES

Indexing terms: Glass, Hysteresis, Measurement, Radiation and radiation effects

To investigate the mechanisms involved in ferromagnetic metallic glasses, we have performed heavy-ion irradiation, during which the changes in magnetic properties have been studied *in situ* as a function of ion dose. The object of this paper is to describe the experimental set-up to record *in situ* $B(H)$ loops and initial permeability μ_i of Metglas 2705 MN toroids.

Soft ferromagnetic glasses are increasingly used in various applications such as low-loss transformers, magnetic heads, transducers, fluxgates and magnetometry. To optimise these materials, thermal and magnetothermal treatments have been studied.[1,2,3] The study of the influence of defects on magnetic properties is important for a better understanding of the mechanisms involved. Towards this end, we have investigated the irradiation of a metallic glass by 2·6 GeV krypton ions in GANIL, Caen at liquid nitrogen temperatures (77 K). Other work has shown that a radiation dose threshold exists in amorphous materials, after which a change of physical properties appears.[4,5,6] We chose to irradiate a low-coercivity non-magnetostrictive amorphous alloy, particularly designed to be used in fluxgate-type magnetometers. The novel purpose of this experiment was to make *in situ* magnetic measurements as function of flux up to $10^{13}\,cm^{-2}$. The $B(H)$ and μ_i measurements were made at 2 kHz; this is the core excitation frequency of a fluxgate magnetometer which has been the object of previous studies at the same frequency.

A schematic diagram of the automatic measurement system is presented in Fig. 1. Nine toroids of type 2705 MN amorphous alloy (Allied Signal Inc., USA) were piled up normal to the ion beam (sample dimensions: inner diameter 10 mm, outer diameter 15 mm, 15 μm thick). Six of these were chosen for the *in situ* measurements.

The irradiation sequences were 20 s of irradiation followed by 180 s with the beam off, during which the appropriate measurements had to be performed. Before each irradiation period μ_i and $B(H)$ were recorded for the six samples after a cooling period (Fig. 2). For that, two coils were wound on each of the six chosen samples, one primary coil and one secondary coil of thin copper wire. The six primary coils fed by an alternating variable current i were mounted in series with a resistor R to provide each sample with the same sinusoidal excitation H. Each primary coil created an excitation

$$H = \frac{ni}{2\pi r}$$

where n is the number of terms on the primary coil, i the current and r the mean radius of the toroid.

The voltage V measured at the R terminals was $V = Ri$, which can be written as $V = R(2\pi rH/n)$; thus V is proportional to H.

Each secondary voltage e was of the form:

$$e = -\frac{d(NBS)}{T}$$

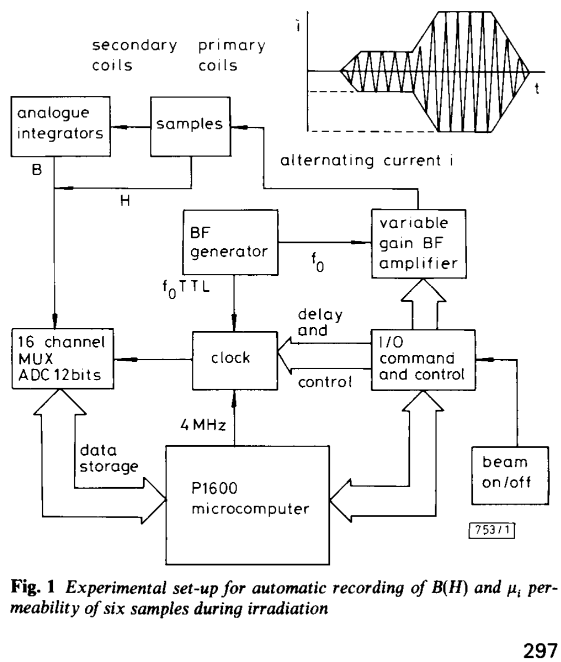

Fig. 1 *Experimental set-up for automatic recording of $B(H)$ and μ_i permeability of six samples during irradiation*