CWF92 Fig. 3. Spectrum from gas discharges in the initial phase of a laser-induced electric breakdown.

will grow to one of the electrodes. A fast transportation of charges from the electrode to the bubble gives energy to a new streamer starting against the other electrode and when contact is established breakdown follows. In Fig. 2 the current and the PMT-signal from the laser-triggered electric breakdown process is seen. The events corresponding to the model are pointed out.

The light to the OMA is delayed in a 200-m optical fibre before going through a spectrometer. The spectrum is then detected by a gated and intensified diode array. The fibre optical delay to the OMA has two distinct advantages—a short (10 ns) light pulse, e.g., from a gas (partial) discharge, can be analysed although the gating electronics needs about 100 ns to respond. A region arbitrarily close in time to the EBD may be studied by triggering on the EBD itself and analysing the delayed light. Figure 3 shows a spectrum from the breakdown arc where C₂ and H-lines are clearly visible.

*ABB Corporate Research, S-721 78 Västerås, Sweden

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CWF93

Polarisation-sensitive coherent anti-Stokes and spontaneous Raman spectroscopy of calix[4]arene films

A. G. Vardanyan, N. F. van Hulst, J. Kanger, C. Otto, J. Greve, *Applied Optics group, Faculty of Applied Physics, University of Twente, P.O. Box 217, 7500 AE Enschede, The Netherlands*

Novel organic molecules with high non-linear optical properties are an important subject of investigation because of their potential application in optical communication, frequency conversion, etc.¹ Here,

CWF93 Fig. 1. Polarization sensitive CARS spectra of 20 mg/ml calix[4]arene in chloroform (dots), fitted spectra (lines) and residual spectra (bottom), for different angles of the polarization analyser.

CWF93 Table 1. Depolarization ratios, estimated from spontaneous Raman and PS-CARS experiments. (*—chloroform line.)

Ω , cm ⁻¹	ρ CARS	ρ Raman
1032	—	0.27
1096	0.25	0.23
1214*	0.7	0.71
1265	0.23	0.2
1299	0.24	—
1345	0.25	0.26
1449	—	0.5
1494	—	0.23
1523	—	0.46
1585	—	0.52

we present the experimental results of spontaneous Raman, polarisation sensitive CARS (PS-CARS) and waveguide CARS of the newly synthesised organic molecule tetranitro-tetra-(n-propoxy)calix[4]arene (C₄₀H₄₄N₄O₁₂) in thin films. For assignment of most specific strong Raman bands of calix[4]arene, a comparative analysis and different derivatives of this molecule were used. In addition, the depolarisation ratios for most of the bands were estimated by polarisation sensitive spontaneous Raman and CARS independently. Several strong bands are present in the Raman spectrum of calix[4]arene: $\Omega = 1095$ cm⁻¹, $\Omega = 1265$ cm⁻¹, $\Omega = 1340$ cm⁻¹, $\Omega = 1584$ cm⁻¹. The strongest band at $\Omega = 1344$ cm⁻¹ ($\rho = 0.25$) corresponds to the symmetric NO₂ stretch. In Fig. 1 the PS-CARS spectrum for calix[4]arene in chloroform (C = 20 mg/ml) is shown. The result of fitting the spectrum with depolarisation ratios, taking into account the various settings of the polarizers is also shown. The observed line shape changes at different analyser settings around the position of background suppression illustrate the polarised character

CWF93 Fig. 2. Raman spectra of calix[4]arene in a waveguide for TM-mode excitation, for both oriented (poled) and non-oriented samples.

of the different bands. For example, the different dispersive shape of the chloroform band at $\Omega = 1214$ cm⁻¹ with $\rho = 0.7$ deviates from the bands of calix[4]arene with $\rho < 0.7$. In Table 1 the depolarisation ratios for calix[4]arene, as determined from the polarised Raman and PS-CARS spectra are summarised. The values agree well for both techniques.

Two colour waveguide CARS and Raman spectra of calix[4]arene on a SiO₂/N_y substrate (refractive index $n = 1.73$) were measured. To this end calix[4]arene was dissolved in chloroform and spin coated on the SiO₂ waveguide. Typical thickness of the calix layers was about 30 nm. The strongest band at 1342 cm⁻¹ was observed where the background was reduced by polarisation suppression for the specific mode combination in the waveguide. The third order nonlinear susceptibility $\chi^{(3)}$ which determines the CARS signal can be written as $\chi^{(3)} = \chi^{NR(3)} + \chi^{R(3)}$, where $\chi^{NR(3)}$ and $\chi^{R(3)}$ are the nonresonant and resonant part, respectively. The non-resonant part of the third order susceptibility of SiO₂/N_y was determined using the $\chi^{R(3)}$ of a polystyrene waveguide as a reference.² The measured spectra were fitted by a nonlinear least square fit procedure giving a resonance-enhanced value at 1342 cm⁻¹ of $\chi^{R(3)} = 6 \times 10^{-12}$ e.s.u. for calix[4]arene.

For investigation of orientational effects in thin films spontaneous Raman was used. Waveguides of calix[4]arene in PPMA were prepared. The molecules were oriented by corona poling.¹ Raman spectra for oriented and non-oriented samples are distinct for different modes of laser excitation (TE or TM). In Fig. 2 the Raman spectra of calix[4]arene in a waveguide, for TM mode excitation, in the case of an oriented and non-oriented film is shown. Different line intensity ratios between various bands of calix[4]arene can be observed. Especially for side group vibrations the observed difference is more than a factor of two.

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CWF94

Wavelength dispersion of the Kerr effect in optical fibres

J. Yao, J. Xu, A. J. Rogers, *Department of Electronic and Electrical Engineering, King's College London, University of London, Strand, London, WC2R 2LS UK*

It is important to determine the dispersion of the Kerr effect in optical fibres for application to fibre communication and fibre sensors; little information on this effect presently exists in the literature. The Kerr coefficient K , has been found to vary with material, wavelength, and temperature. The classical Havelock's Law¹ has the form of $K = c(n^2 - 1)^2/E^2 n \lambda$ where λ is the wavelength, c is a material constant and independent of wavelength, n is the refractive index, and E is the applied electric field. Havelock's law appears adequate for some materials. It has been verified experimentally by several investigators.^{2,3} In order to measure the very small Kerr coefficient for silica optical fibres, the experimental arrangement in Fig. 1 was used. The Kerr coefficient $K = dI_0/I\pi E^2$ can be measured by detecting the parameters dI_0 , the light intensity variation, I , the total light intensity, E , the applied electric field, and L , the length of the fibre.

A dye laser was used for the measurement in the low birefringence (Lo-Bi) fibre. A Lo-Bi fibre (York), 2.4 m long, with higher order mode cut off at 600 nm, was wound around a brass cylinder which was enclosed by a second cylinder. The gap between the two cylinders (1 mm) was filled with transformer oil and an A.C. voltage (approximately 2.5×10^3 V RMS) was applied. In this way one of the induced optical axes can be arranged, by winding to be parallel with the applied electric field E . The cylinders were immersed in a temperature-controlled oil bath ($25.0^\circ \pm 0.1^\circ$ C). The detection system included a PIN diode, a lock-in amplifier and a computer, to collect the data. For each wavelength, 100 readings were taken and then averaged to increase the signal to noise ratio. A photograph of the frequency-doubled Kerr signal is shown

CWF94 Fig. 1. The experimental arrangement for measurement of the Kerr coefficient. The linearly polarised monochromatic light was launched into the optical fibre at an angle of 45° to the induced birefringence axes (by the electric field E) X, Y. The Y direction is parallel with the applied electric field.

CWF94 Fig. 2. The modulated signals. Upper trace (CH₂): applied voltage, 40 Hz; lower trace (CH₁): Kerr effect signal, 80 Hz.

CWF94 Fig. 3. Dispersion of the Kerr coefficient. Symbol "X": measurement for Hi-Bi fibre (the error bars show 10% error). Symbol "■": measurement for Lo-Bi fibre (the error bars show approximately 15% error).

in Fig. 2. The problems encountered in this measurement were: (1) The circular birefringence caused by fibre-twisting is difficult to compensate. (2) The fibre input and output have birefringence axes resulting from the stress applied to the fibre and this may not coincide with the electric-field-induced fibre axes.

A D-type Hi-Bi fibre (Andrew) was used to avoid the problems. The flat face of the cladding is mode parallel with one birefringence axis of the fibre. The fibre (50-cm long) jacket was carefully stripped away and it was then placed carefully between two flat metal (steel) plates, with flat face of the fibre parallel to the plates so that the fibre axis was arranged to coincide with the E direction. In order to detect the very small signal dI_0 , a photomultiplier and semiconductor lasers operating at 633 nm, 670 nm, 685 nm, and 780 nm were used as the detector and light sources, respectively. A temperature controller was employed to vary the laser diode wavelengths. The voltage across the gap was about 1.2×10^3 V RMS.

The Kerr coefficients of Lo-Bi and Hi-Bi optical fibres were measured over a range of wavelengths from 633 nm to 690 nm, and from 633 nm to 785 nm, respectively. The dispersion curves for the Kerr coefficient in Lo-Bi and Hi-Bi fibre are illustrated in Fig. 3 and indicate the reduction in the value of the coefficients as the wavelength increases.

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CWF95

All-optical modulation and amplification via cascading in lithium niobate waveguides

I. Torelli, G. Assanto, S. Trillo,* *Department of Electronic Engineering, University of Rome, Via Eudossiana 18, 00184 Rome, Italy*

Cascading of quadratic nonlinearities allows us to obtain large phase shifts for all-optical processing.^{1,2} The tensorial nature of the second-order susceptibility lends itself to a richer set of interactions than the scalar ones analysed to date, and we propose novel schemes for all-optical modulation and transistor action based on the coherent interaction between two orthogonally polarized fundamental waves and the generated second-harmonic (2ω) in a y -propagating z -cut Lithium Niobate waveguide. For two type I interactions, the coupled-mode equations can be case in the form:

$$\begin{aligned} \frac{dA_j}{d\xi} &= -i\chi_j A_j^* B + i \frac{k_j}{2} A_j \\ \frac{dB}{d\xi} &= -\frac{i}{2} \chi_1 A_1^2 - \frac{i}{2} \chi_2 A_2^2, \quad j = 1, 2 \end{aligned} \quad (1)$$

with $A_j(\xi)$ and $B(\xi)$ slowly varying amplitudes at ω and 2ω , respectively, such that $0.5(|A_1|^2 + |A_2|^2) + |B|^2 = 1$, $\xi = y d_{31} P^{1/2}$ the normalized propagation distance, $\chi_1 = 1$, $\chi_2 = d_{33}/d_{31} = 3.7$ with d_{31} and d_{33} nonlinear coefficients connecting the fundamental fields to the same z -polarized 2ω wave, $k_j = \Delta\beta_j P^{-1/2}/d_{31}$ normalized mismatches with $\Delta\beta_j = \beta(2\omega) - 2\beta_j(\omega)$ and P the total input power. The d_{3j} coefficients include effective cross-sections calculated over the modal distributions. Although the above nonlinear system is non-integrable, numerically solving (1) with $B(0) = 0$ (zero 2ω input) we identified useful regions for operation. We describe a) the possibility of varying the relative phase ϕ_{21} between the two orthogonal fundamental components entering the structure, in order to control the throughput characteristics at ω ; b) transistor action amplifying the z -polarized signal at the expenses of the x -polarized pump. Figure 1 shows the ω throughput at the end ($y = L$) of the crystal vs ϕ_{21} in two cases: i) modulation imposed onto the amplified signal; ii) modulation imposed onto the pump. In the last case the phase-matching ($\Delta\beta_1 = 0$) allows large energy transfer to the initially weak signal, and in both cases one of the fundamental outputs (along x or z) is modulated by $\sim 90\%$ for $\Delta\phi_{21} \sim \pi/4$. Figure 2 shows x -throughput and amplification vs x -polarized input, normalized to the initial pump-power. Transistor action with large gain is apparent.

Adopting quasi-phase-matching and temperature index-tuning for z - z - z and x - x - z interactions, respectively, we calculated that powers around 200 W are required for some of the processes describing using a 5-mm-long Ti:indiffused LiNbO₃ channel operating at 1.55 μ m slightly above room temperature.

*Fondazione Ugo Bordon, Via B. Castiglione 59, 00142 Rome, Italy