Invited talk at NLGW'96, Cambridge

ELECTRIC FIELD POLING OF QUASI-PHASE-MATCHED OPTICAL FIBRES

1249

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Abstract

Electric field poling of silica glass provides the prospect of efficient second-order nonlinear interactions in optical fibres. Recent advances in quasi-phase-matched second harmonic generation in electric field poled silica fibres are reviewed.

ELECTRIC FIELD POLING OF QUASI-PHASE-MATCHED OPTICAL FIBRES

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Ten years have passed since the discovery of photoinduced quasi-phase-matched second harmonic generation in optical fibres [1-3]. However, until fairly recently, second harmonic generation in optical fibres has been more of scientific than practical interest, owing to the low levels of induced nonlinearity ($\sim 10^{-3}$ pm/V, which is four orders of magnitude less than in inorganic crystals, e.g. lithium niobate). The mystery of photoinduced $\chi^{(2)}$ gratings was finally solved on the basis of the coherent photogalvanic effect [4]: a high (10^{4-5} V/cm) spatially oscillating electrostatic field appears in glass as a result of charge separation induced by coherent photocurrent, oscillating with a period determined by the coherence length; this electric field produces a quasi-phase-matching $\chi^{(2)}$ grating in proportion to $\chi^{(3)}$. The conversion efficiency reported in the first experiments on photoinduced SHG - $\sim$5% from a peak pump power of $\sim$20 kW - is still among the highest conversion efficiencies achieved so far in optical fibres. The reasons for these relatively high conversion efficiencies has to be searched in the long length (tens of centimetres) and good uniformity of the photoinduced gratings.

During the past five years a number of glass poling techniques have emerged that produce second-order nonlinearities approaching 1 pm/V (very close to the value of nonlinearity in LBO, which is a crystal widely used for pulsed frequency conversion). These new poling techniques are: thermal poling at 250-300 °C under an applied electrical field (the second-order nonlinearity appears in a thin layer just under the anode) [5], corona poling of glass waveguides [6], charge implantation by exposure to an electron-beam [7] and UV - excited poling [8]. To date the thermal poling technique has shown the most promising results in poling of silica fibres [9]. However a problem encountered in thermal poling is the spreading out of the poled regions caused by air breakdown that occurs when one attempts to create quasi-phase-matching $\chi^{(2)}$ gratings [10,11]. Two solutions are possible to sidestep this problem: 1) electron beam or UV light can be used for selective erasure of uniformly poled sample [10]; 2) thermal poling in vacuo, using a patterned electrode, can create periodic $\chi^{(2)}$ patterns [12].

Recently, periodically patterned second order nonlinearities have been created in optical fibres by thermal poling in vacuo and cw quasi-phase-matched frequency conversion to the blue has been demonstrated [12]. The maximum blue light power detected was $\sim$400 pW, corresponding to a fundamental power in the fibre of $\sim$100 mW. Here we report recent developments in cw blue light generation in poled optical fibres. An increase of a factor $\sim$10 in the conversion efficiency in comparison with the previous results has been obtained.
A cw Ti:sapphire laser was used to test the fibres thermally poled in vacuo via a periodic anode 6 mm long. Fibres, whose core region was located between 1 and 4 μm from the side-polished surface, were tested. The dependence of the SH power on the pump wavelength in the fibre with a small (1 μm) core-surface distance show a well defined main peak ($LP_{01}{}^{\omega}$ - $LP_{01}{}^{2\omega}$ interaction) at 880 nm of $\sim$2.6 nm bandwidth, together with a weak side peak at 860 nm ($LP_{01}{}^{\omega}$-$LP_{11}{}^{2\omega}$ interaction) (Fig.1). The measured bandwidth for the phase-matching peaks

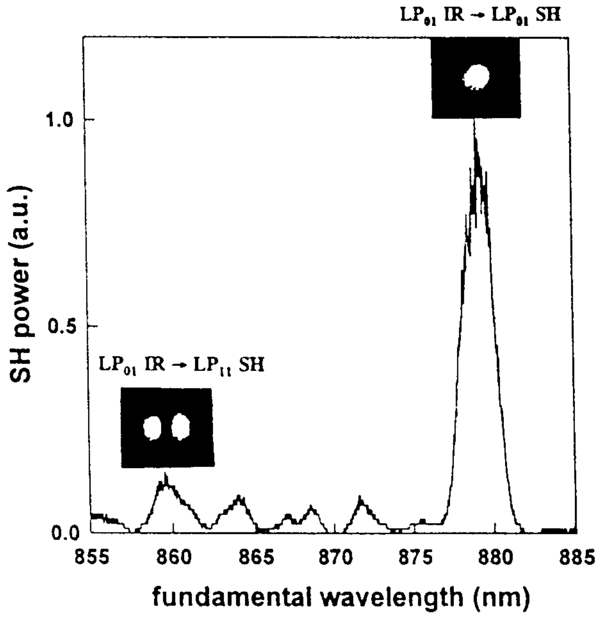

Fig.1 SH power vs fundamental wavelength in QPM fibre.

is approximately 2 times larger than the theoretical estimate. The maximum blue light power detected was ~10 nW corresponding to a fundamental power in the fibre of ~230 mW. We have observed that in fibres with a core-surface distance greater than 1 μm the $LP_{01}{}^{\omega}$-$LP_{11}{}^{2\omega}$ interaction could be stronger than the $LP_{01}{}^{\omega}$-$LP_{01}{}^{2\omega}$ interaction. From these measurements we can estimate the amplitude of the $\chi^{(2)}$ grating to be of ~0.02 pm/V which is ~50 times smaller than the expected value of ~1 pm/V. The quality of the $\chi^{(2)}$ grating was also tested by using a pump propagating perpendicular to the fibre. The fibre showed well defined periodic structure regions together with the regions where the nonlinear grating was absent. We also tested uniformly poled fibres by using a tunable Ti:sapphire laser. Maker's oscillations of SH signal were observed (Fig.2). These measurements suggest a value for the

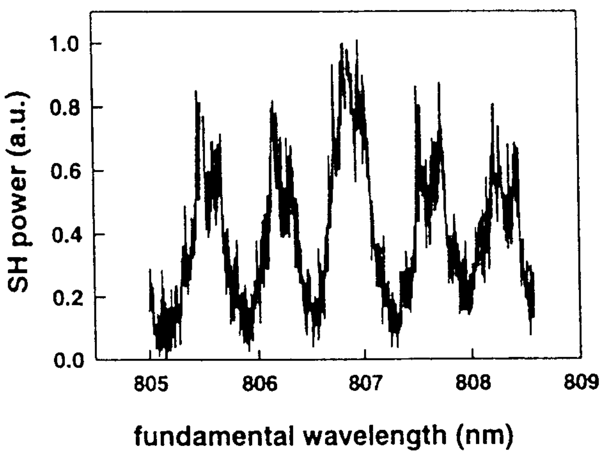

Fig.2 SH power vs fundamental wavelength in uniformly poled fibre.

$\chi^{(2)}$ in the uniformly poled fibre of ~1.4 pm/V and point out that considerable improvements in the conversion efficiency in quasi-phase-matched fibres are expected by improving the quality of the periodic structures.

Recently, we observed a new phenomenon in fibres where an electrical field was applied via internal electrodes: the electrically induced growth of $\chi^{(2)}$ gratings [13]. For applied voltages higher than ~2 kV an unexpected increase of the SH signal was observed and conversion efficiencies as high as ~2% were achieved for a pump peak power of ~1 kW. After disconnecting the voltage, the SH signal rapidly decreased, then gradually increased, and finally decreased again (Fig.3). This process can be periodically repeated by switching-on

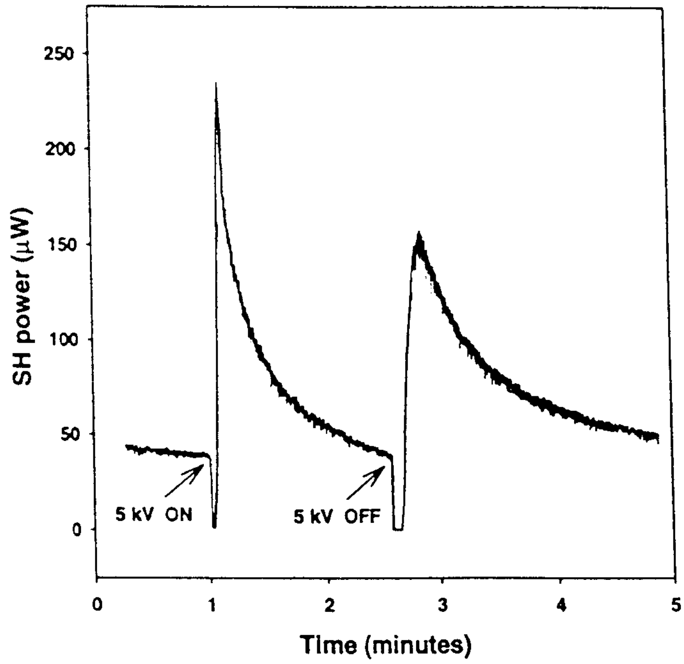

Fig.3 SH power vs time in the ON-OFF electric field regime in the fibre with internal electrodes.

and switching-off the voltage. We believe that the observed phenomenon can be explained by a new effect - electrically stimulated coherent photogalvanic effect (ESCPE). The physical mechanism responsible for ESCPE may consist in an increase, due to electric field, of the probability of optical transitions responsible for coherent photocurrent, e.g. interference between two-photon absorbtion (ionization) and one-photon absorption (ionization).

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