# NONLINEAR MODE-COUPLING IN MULTIMODE OPTICAL FIBRES: THE GENERATION OF THE FEMTOSECOND RAMAN SOLITONS

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## Abstract

It is shown that in a nonlinear regime a multimode fibre acts as a single-mode fibre at higher Stokes wavelengthes. This effect leads to high peak power of Raman solitons due to large core area of the multimode fibre.

It is well-known that in the linear regime, the mode-coupling in a long, low-loss multimode fibre leads to an almost uniform mode power distribution [1]. On the other hand, in some nonlinear systems the power is distributed among a few low order modes [2]. So it seems very attractive to study a temporal and spatial characteristics of the multimode fibres in the nonlinear regime.

Towards this goal we have studied the pertinent characteristics of the stimulated Raman scattering (SRS) in multimode optical fibres. The experimental set-up included a cw mode-locked and Q-switched Nd:YAG laser, the radiation from which was launched into a multimode graded-index fibre ($\Delta n=13\cdot 10^{-3}$, $2a=45\ \mu m$). Temporal characteristics of the output radiation were obtained by a zero background second-harmonic autocorrelation technique. The spatial characteristics were measured by scanning a single-mode fibre with a known field distribution across the output end of the test fibre. The spectra of the output radiation were taken with a grating monochromator and a germanium photodiode.

Fig.1 (solid curve ) shows the SRS-spectrum in 50 m length of multimode fibre. The continuous spectrum in the negative group velocity dispersion range is similar to that of single-mode fibre which is represented by dashed curve in Fig.1. Since the continuous SRS-spectrum in a single-mode fibre is due to modulational instability and Raman scattering that lead to the Raman soliton generation [3] it seems rather plausible to anticipate something similar in the multimode fibre. The temporal measurements confirm this assumption. Fig.2 shows autocorrelation functions at 1.6 $\mu$m. Assuming $sech^2$ - shape the pulse duration is 90 fs for 50 m length of the fibre. Such short pulses can be obtained in a broad spectral region ( see insertion in Fig.2, where curve 1 - pulse duration, curve 2 - correlation function contrast, i.e. peak to pedestal ratio).

Pulse duration measurements in a long multimode fibre have shown that these pulses are Raman solitons: the pulse spreading is due to linear losses ( see Fig.2 ).

The results of the spatial distribution measurements agree qualitatively with those from Ref.4,5. If at the pump wavelength the power distribution is the result of the superposition of many modes ( Fig.3, curve 1) then at 1.6 $\mu$m the power distribution is corresponded to the fundamental $HE_{11}$-mode.

The latest conclusion has been proved by the spatial coherence measurement which demonstrated the complete spatial coherence of the multimode fibre output field at Stokes wavelength.

The significance of this result is two fold. Firstly, there is a possibility of using the multimode fibres in long distance communication systems and sensors. Secondly, the fundamental soliton power in a multimode fibre is much greater than in a single-mode fibre. In our case the Raman soliton peak power is 30 kW in contrast to 5 kW for the single-mode fibre case.

At present, the nature of the physical mechanism of the Raman soliton generation in multimode fibres is not clear. Therefore we will describe some experimental results which could be useful for future understanding.

1. SRS temporal characteristics in a multimode fibre are

similar to those in a single-mode fibre, namely in a zero chromatic dispersion region modulational instability occurred and the correlation function contrast increased with the wavelength.

2.The spatial width of the power distribution at the output end of the multimode fibre slowly decreases with wavelength and at 1.5 $\mu$m the radiation is transferred by solely the fundamental mode. It should be noted that recently the same effect has been explained by self-focusing in a waveguide media [4,5], but satisfactory theory is absent. Moreover, mode-reduction effect has taken place only at Stokes wavelength and has been absent at the pump wavelength, while intensities were approximately the same.

3.Power distribution at Stokes wavelengths are practically independent of pump power.

4.Stokes power distributions did not depend on a fibre length: for lengths between 10 - 500 m, the power distribution at $\lambda$ > 1.5 $\mu$m corresponded to a fundamental mode and spot size was independent of the fibre length.

In our opinion the main reason for such nonlinear characteristics of the multimode fibre is a nonlinear mode-coupling, but the physical nature of this phenomenon is not understood.

Summary. We have produced femtosecond Raman solitons from a multimode optical fibre. It is shown that in nonlinear regime a multimode fiber acts as a single-mode fiber at higher Stokes wavelengthes. Peak power of these solitons is much greater than in a single-mode fibre due to the larger core area of the multimode fibre.

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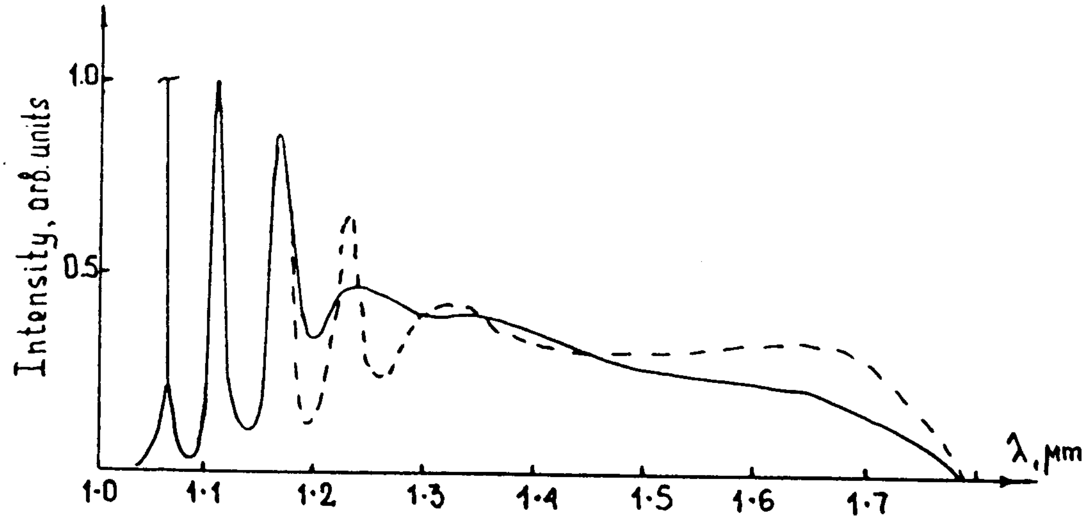


Fig.1

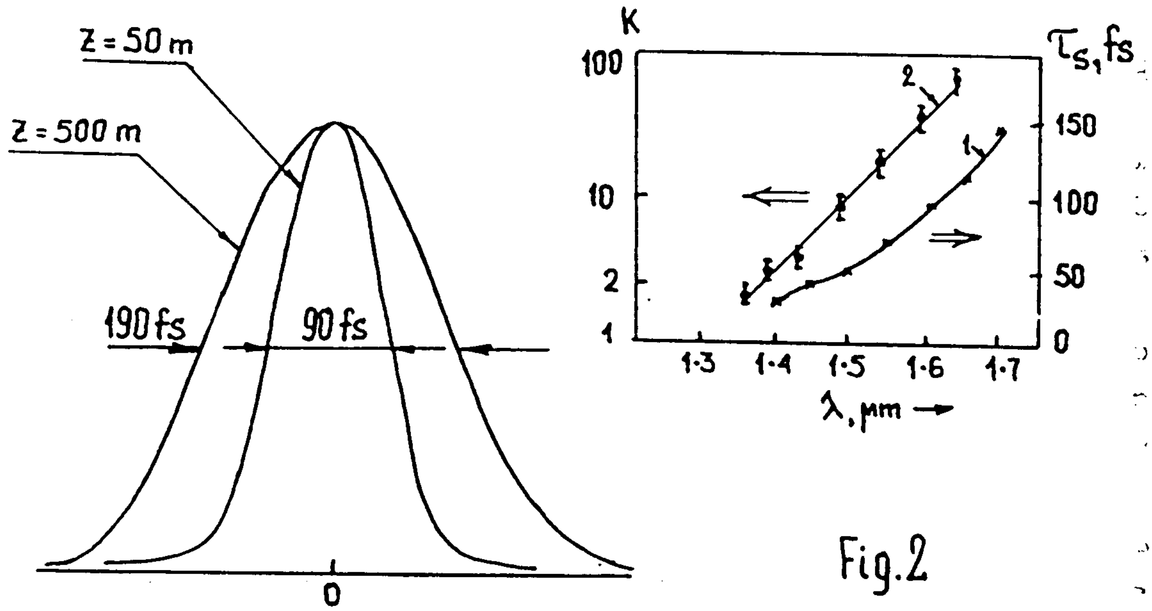


Fig.2

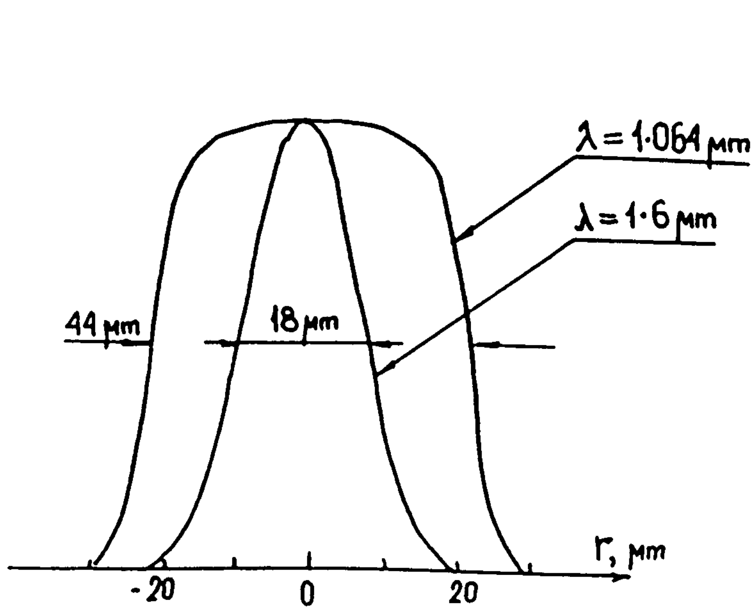


Fig.3