# Demonstration of stimulated Raman scattering in the evanescent field of a tapered nanofiber

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## Summary

We present the first experimental demonstrations of stimulated Raman scattering in the evanescent field of a tapered nanofiber. Given the large choice of available materials for the medium surrounding the nanofibers, this demonstration opens the way to the exploration of a new class of experiments and devices.

## Introduction

Tapered nanofibers are optical fibers stretched until their diameter becomes comparable to the optical wavelength [1]. The guided light exhibits a pronounced evanescent field that extends inside the surrounding medium. Considering that nanofibers can be obtained with lengths up to tens of centimeters, this strong evanescent field can produce significant nonlinearities. This specificity of tapered nanofibers did not escape to previous authors [2]. Such "evanescent nonlinearities" are unique tools to probe the atomic fluorescence of gases [3]. They were also used for spectroscopic measurements [4], but, to our knowledge, were never employed to excite nonlinear wave mixing such as Raman or parametric processes. The difficulty of realizing nanofibers with the required characteristics is probably one reason for which no demonstration was conducted up to now. To evidence this difficulty, based on our modeling [5], we plotted in the following figure the modal Raman gain for a nanofiber immersed in a mixture of toluene and ethanol. The modal gain (expressed in $m^{-1}.W^{-1}$) is plotted versus the nanofiber radius and the fraction volume of toluene in the mixture. Toluene is the Raman medium that is excited on its main line at 1003 $cm^{-1}$; ethanol is used to reduce the refractive index below the one of silica.

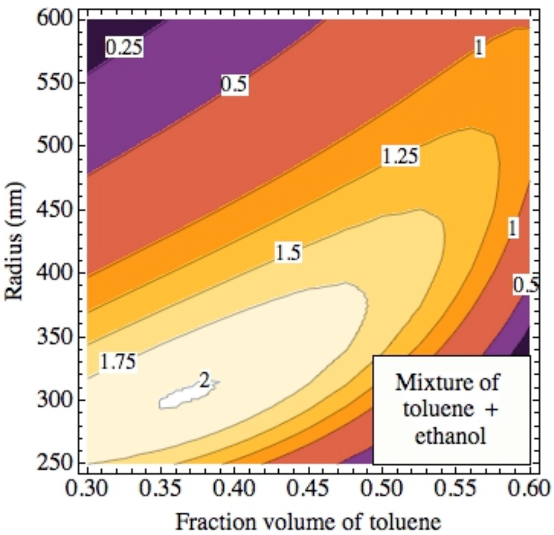


Fig. 1: Raman gain experienced by the guided mode versus the nanofiber radius and the fraction volume of toluene in a mixture of toluene-ethanol. The numbers on the contour lines are the value of the Raman gain in $m^{-1}$ $W^{-1}$. To plot this curve, the Raman coefficient of toluene was taken equal to 3.5 $10^{-11}$ m/W.

The maximum gain is about 2 $m^{-1}W^{-1}$ at a nanofiber radius of about 300 nm. For optical peak powers of a few hundred watts, nanofiber lengths of a few centimeters are thus required to reach the threshold for stimulated Raman scattering [5].

## Experiment and results

The fiber to be pulled (standard SMF-28 telecommunication fiber) is attached at two translation stages. The two translation stages elongate the fiber to create the nanofiber while the heater (a torch supplied by butane gas) softens the central part of the fiber. For the following experiment, we fabricated a nanofiber whose radius is 350 nm over a length of 6 cm. The overall transmission of this nanofiber, including the two tapers required to inject and to collect the light, is 80%. After the pulling process, the nanofiber was immersed inside a tank filled with a mixture of toluene and ethanol with a fraction volume of 50%. We injected the light from a pulsed microlaser at 532 nm. Its repetition rate is 500 Hz, and the pulse duration is 660 ps. The nanofiber was connected to an Optical Spectrum Analyzer. At low power, a single peak at 532 nm was observed. Increasing the power we observed the appearance of the first Stokes of toluene at 562 nm. For an input average power of 300 μW (270 μW estimated in the nanofiber) we measured the spectrum shown in the following figure. Beside the peak at 532 nm corresponding to the pump beam, the first (at 562 nm) and the second (at 595 nm) Stokes of toluene are strongly excited.

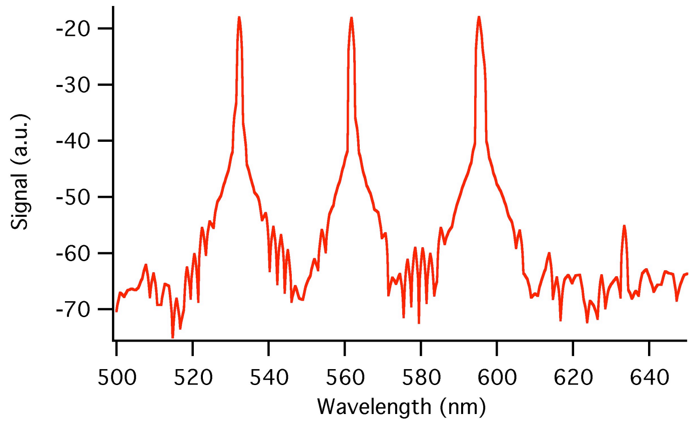


Fig. 2: Spectrum at the output of the nanofiber immersed in a mixture of toluene-ethanol. Besides the peak of the pump beam at 532 nm, the first and second Stokes of toluene at 562 nm, and 595 nm are excited.

## Conclusions

We performed the first demonstration of Raman conversion in the evanescent field of a tapered nanofiber. This experiment was conducted with a low cost subnanosecond microlaser. Although this subnanosecond regime is known to be worse than a picosecond or even femtosecond regime concerning the silica laser damage, we can work well above the Raman threshold without damaging the nanofiber. We thus believe that this first demonstration opens the way to a full range of new experiments using these “evanescent nonlinearities”.

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