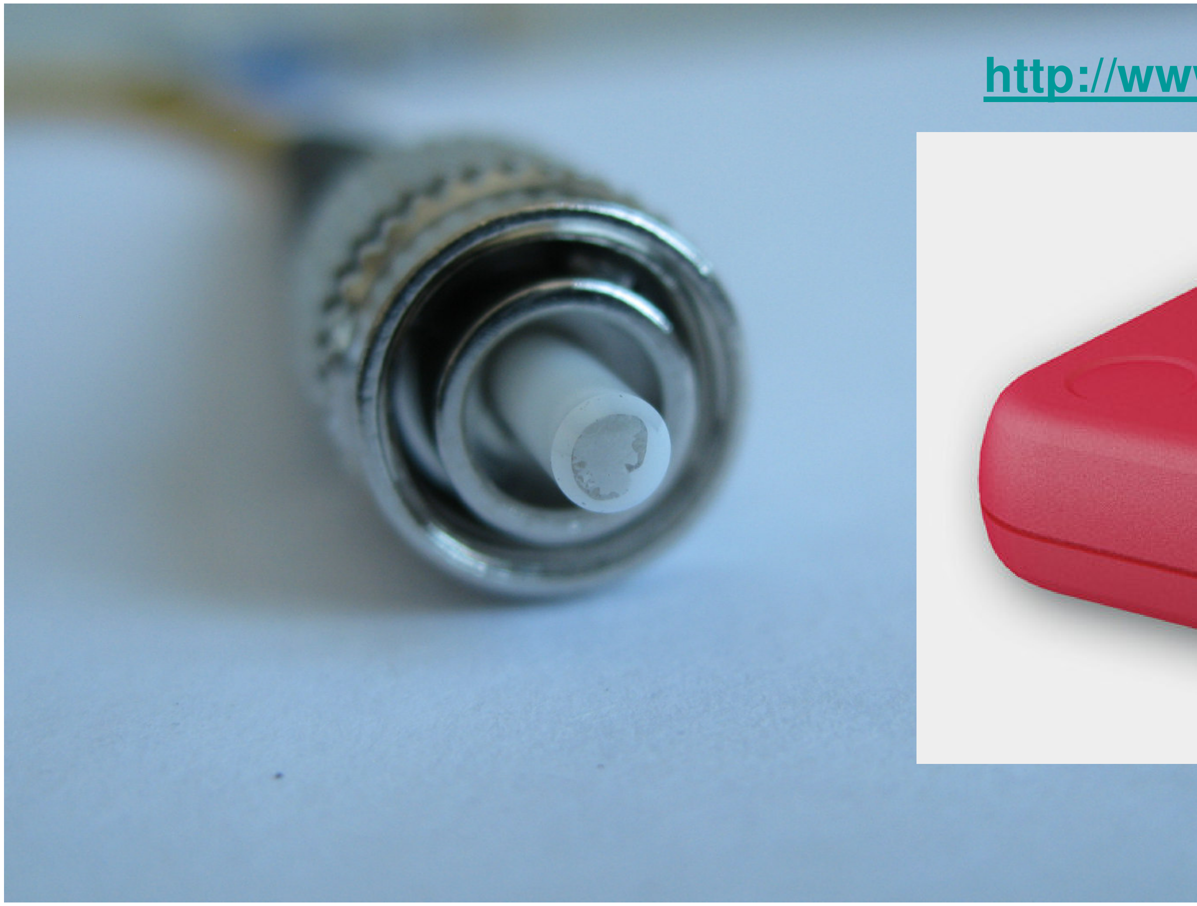


http://www.gpi.ru/nanospectroscopy

Graphene for laser applications

E.D. Obraztsova[1], M.G. Rybin[1], A.V. Tausenev[2], V.A. Shotniev[2], V.R. Sorochenko[1], P.S. Rusakov[1], I.I. Kondrashov[1]

[1]A.M. Prokhorov General Physics Institute, RAS, 38 Vavilov street, 119991, Moscow, Russia
[2]Avesta-Project Limited Liability Company, Troitsk, Moscow Region, Russia

A.M. Prokhorov General Physics Institute of Russian Academy of Sciences http//:www.gpi.ru

GPI RAS is one of the leading physics institutes in Russia.

About 770 persons work there.

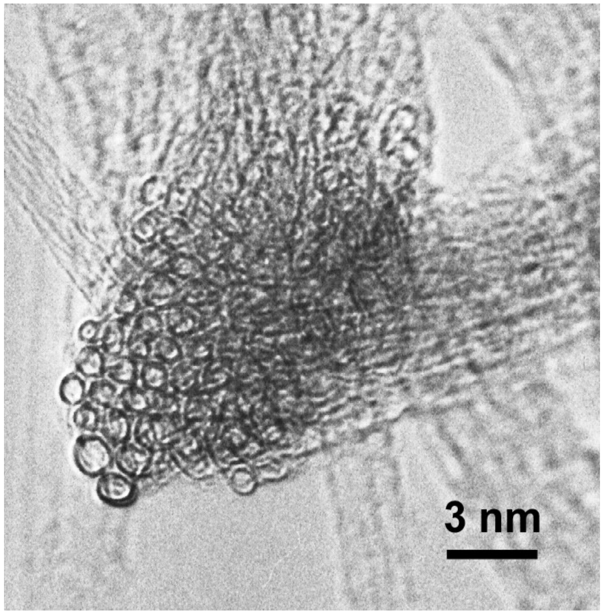
The Nobel Prize in Physics 1964

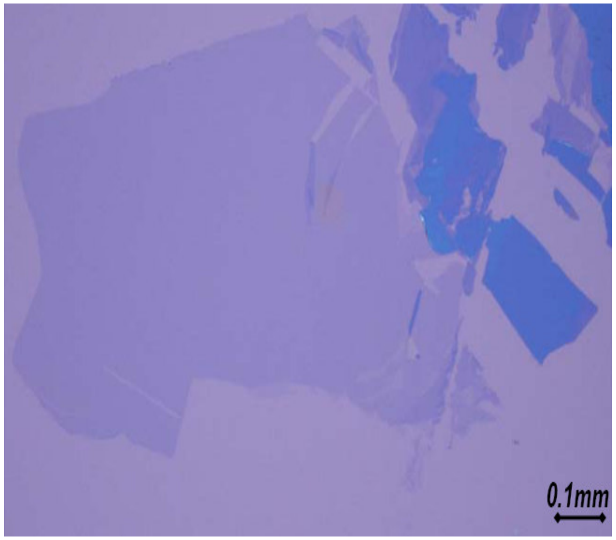
"for fundamental work in the field of quantum electronics, which has led to the construction of oscillators and amplifiers based on the maser-laser principle"

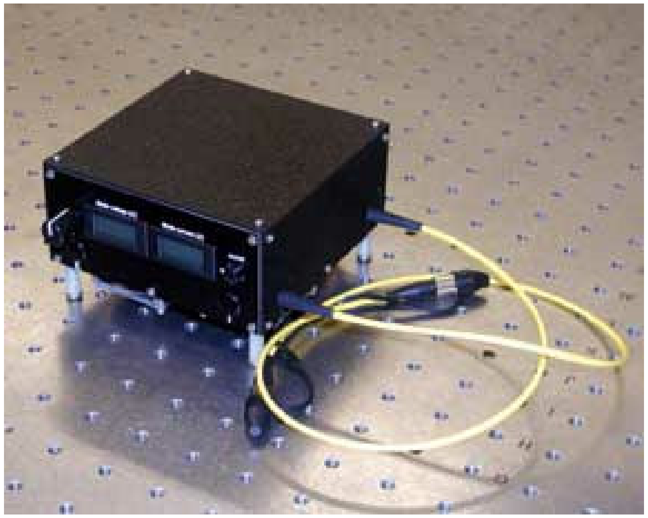
		
Charles Hard Townes	**Nicolay Gennadiyevich Basov**	**Aleksandr Mikhailovich Prokhorov**
1/2 of the prize	1/4 of the prize	1/4 of the prize
USA	USSR	USSR
Massachusetts Institute of Technology (MIT) Cambridge, MA, USA	P.N. Lebedev Physical Institute Moscow, USSR	P.N. Lebedev Physical Institute Moscow, USSR
b. 1915	b. 1922 d. 2001	b. 1916 d. 2002

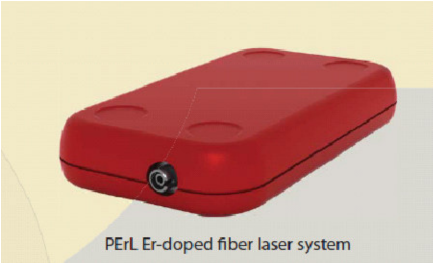
In Stokholm

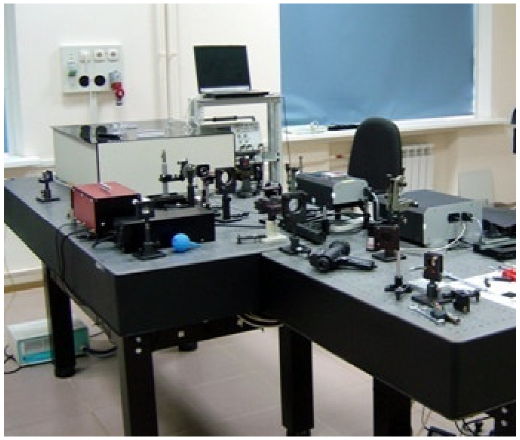
Our main task – **formation of ultrafast non-linear optical elements based on carbon nanotubes for solid state lasers**



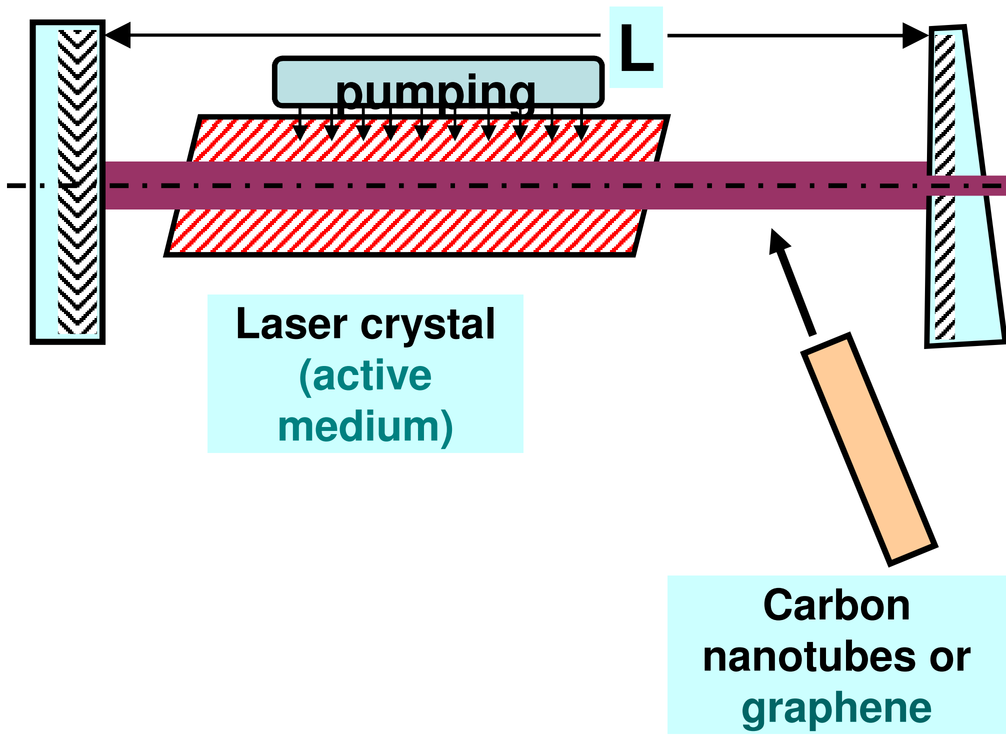




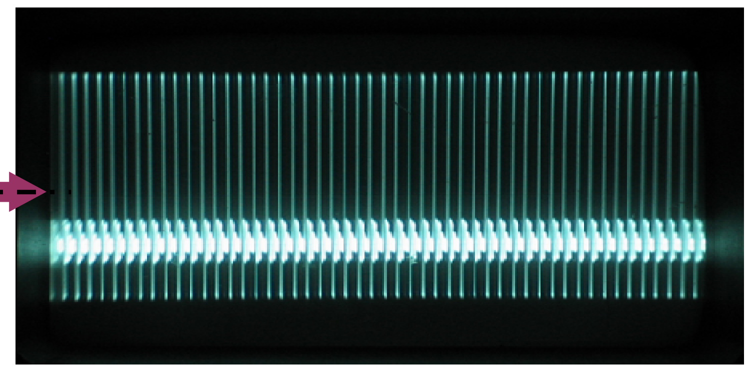


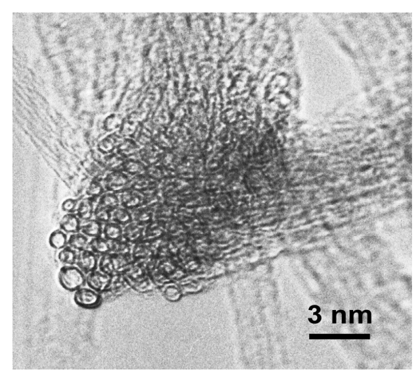


contininious** wave* laser radiation → ***train of femtosecond pulses



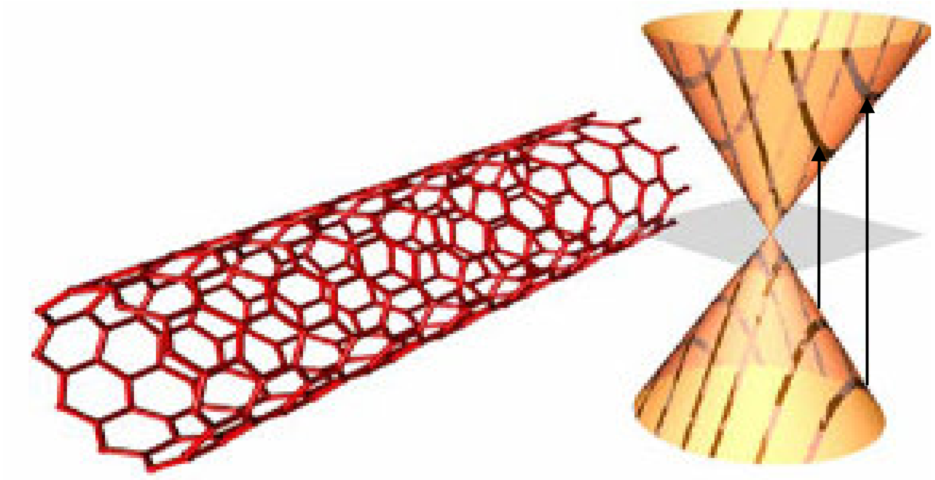
Output radiation

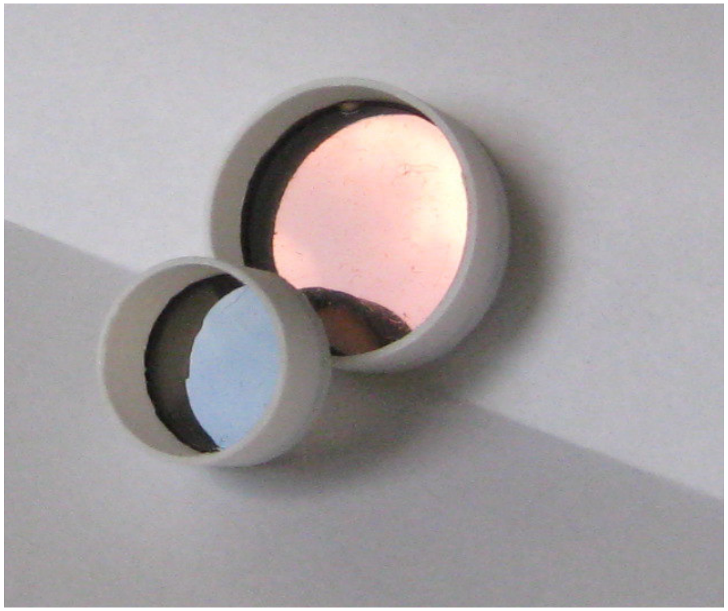


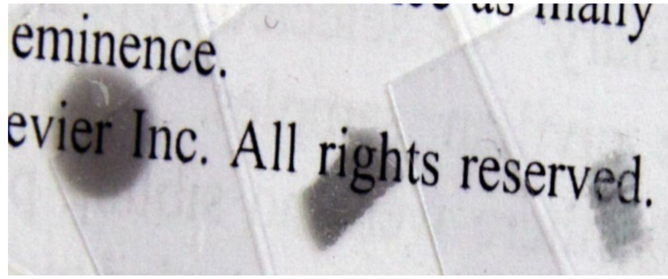


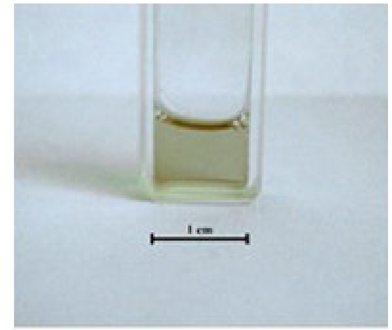
We have started from

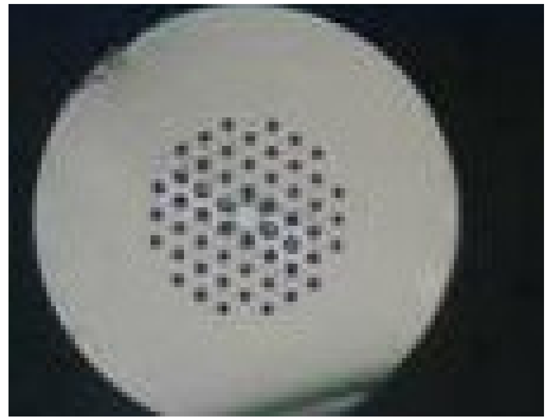
single-wall carbon nanotubes

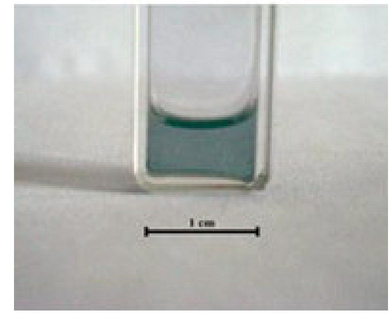








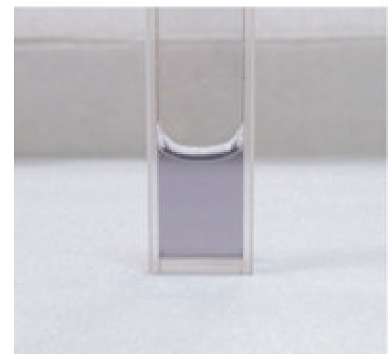


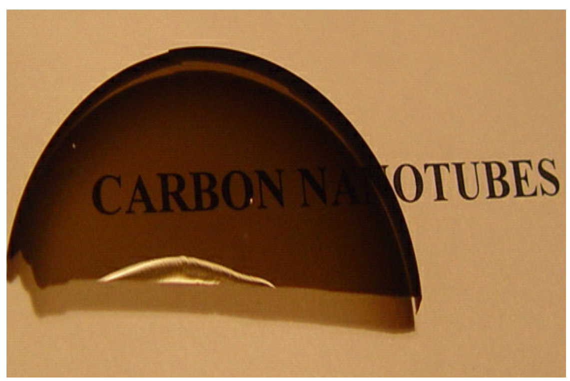


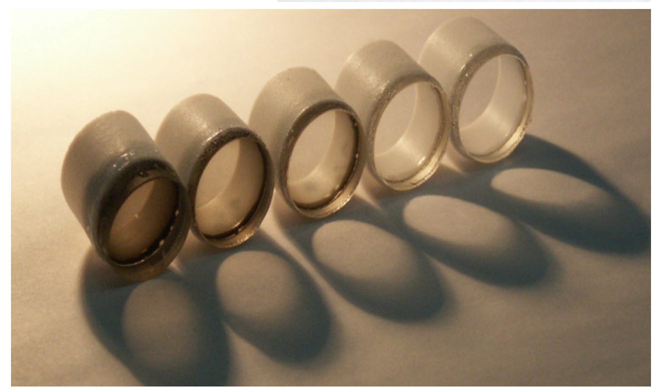
Our work

Different media based on single-wall carbon nanotubes

1.0-2.2 mkm) **http://www.gpi.ru/nanospectroscopy**

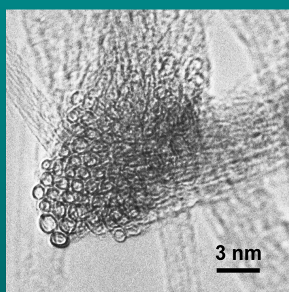


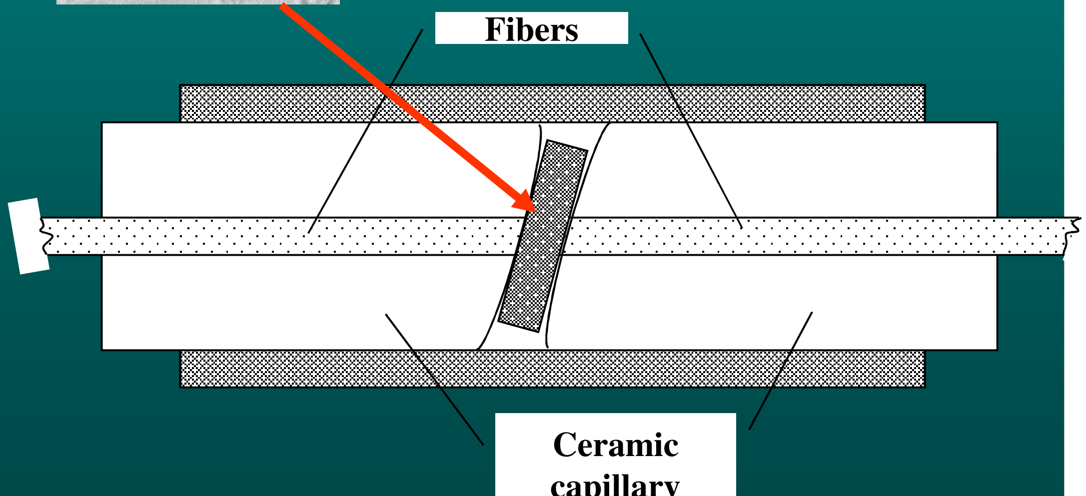


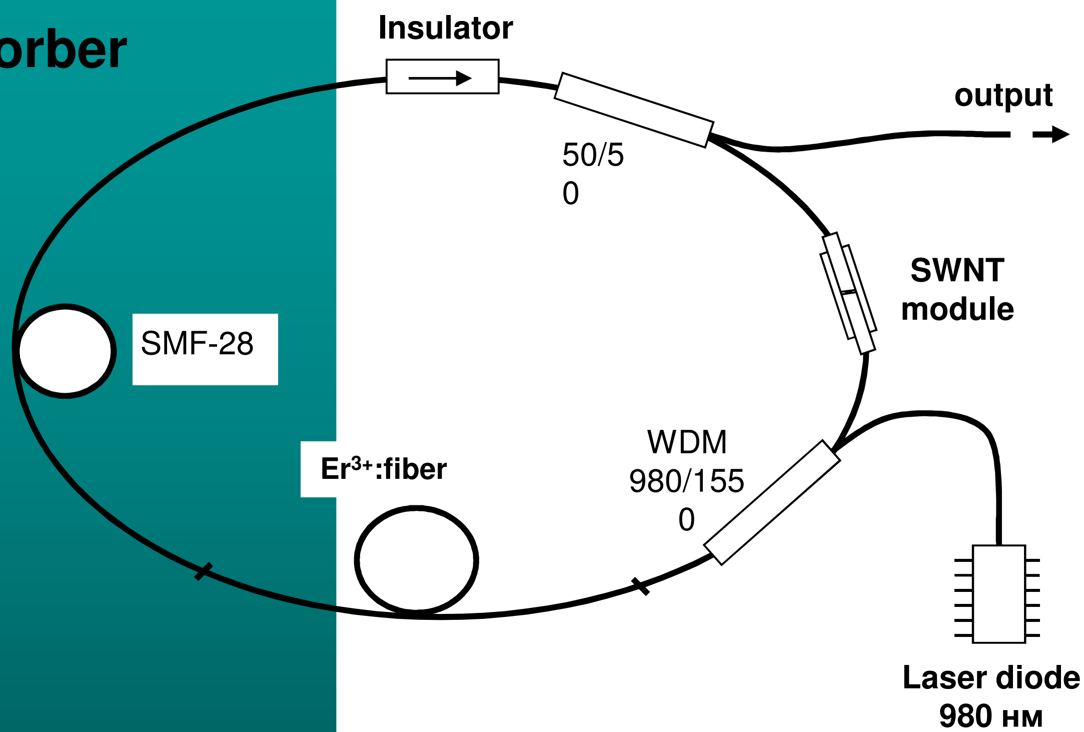


A scheme of Er^{3+}- fiber laser with a ring resonator containing a saturable absorber "arc SWNTs +PvA"

nanotubes

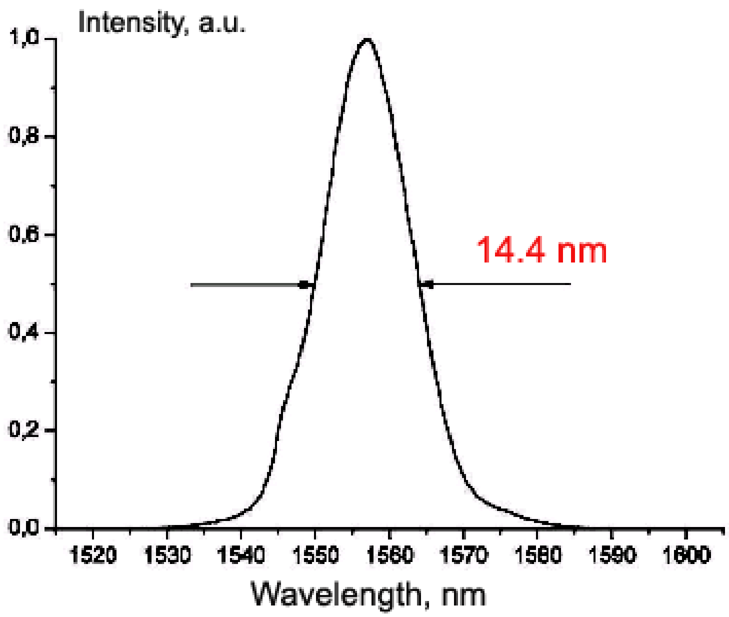


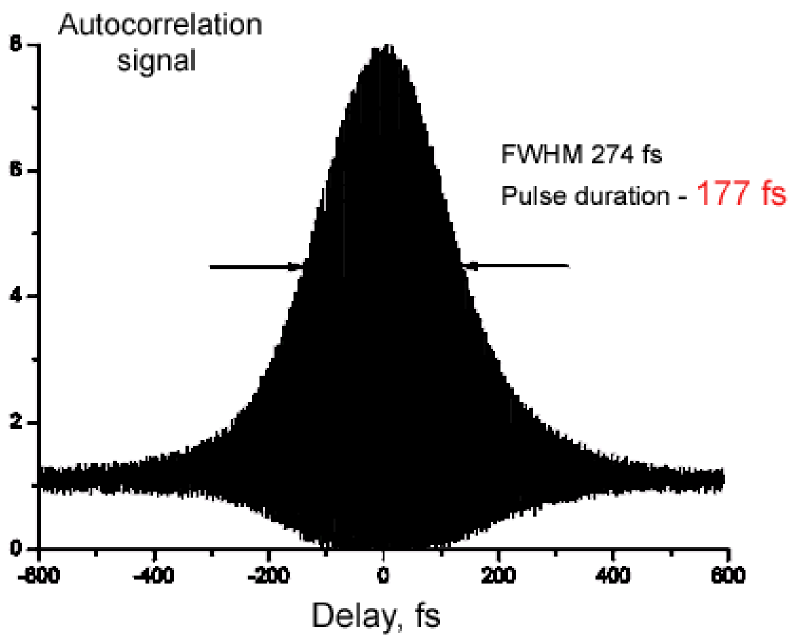




A.V. Tausenev, E.D. Obraztsova, A.S. Lobach et al., *Quantum Electronics 37 (2007) 205-208.*

The SWNT-based media
is not a limiting factor for the pulse duration



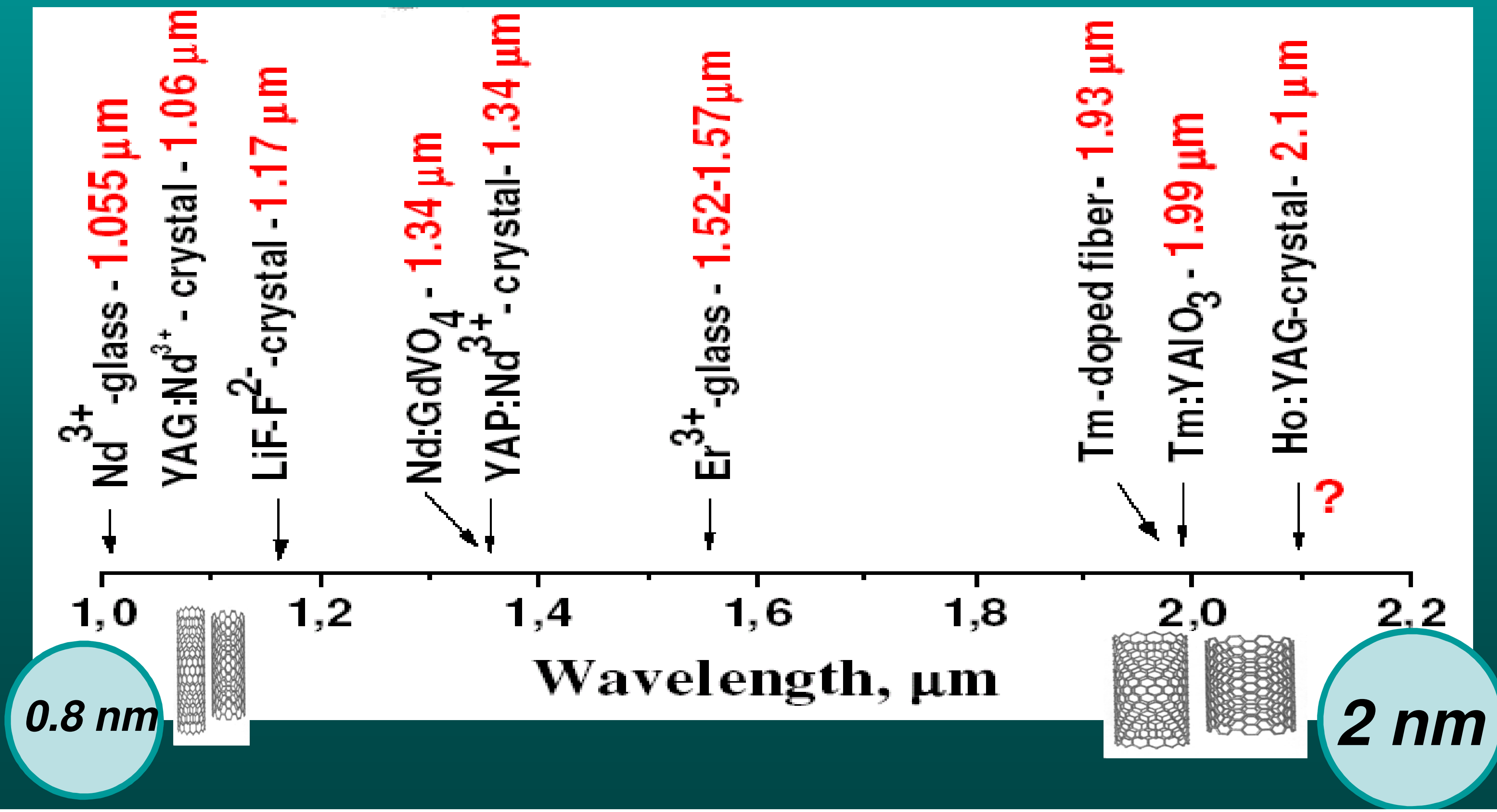


The pulse may be shorten via the resonator optimisation

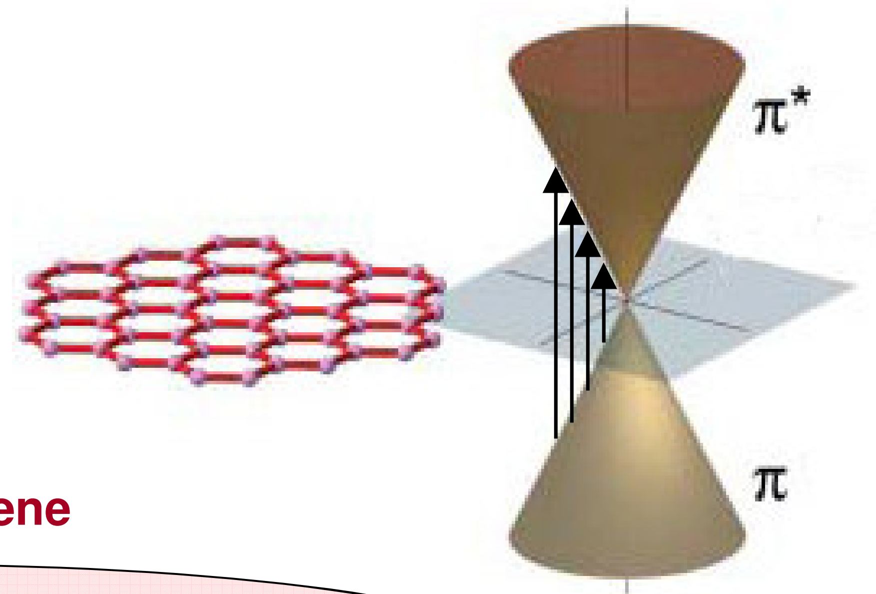
A.V. Tausenev, E.D. Obraztsova et al., *APL 92 (N18) (2008)171113*

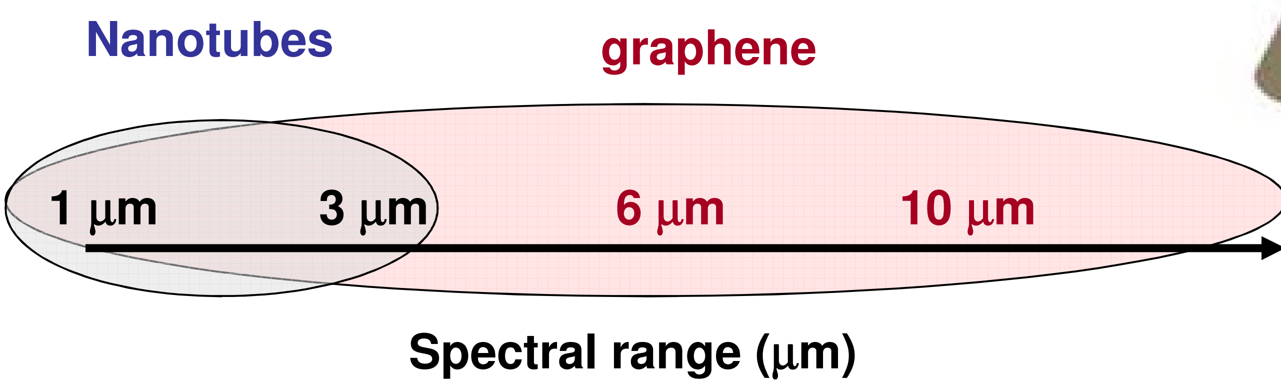
Since 2004

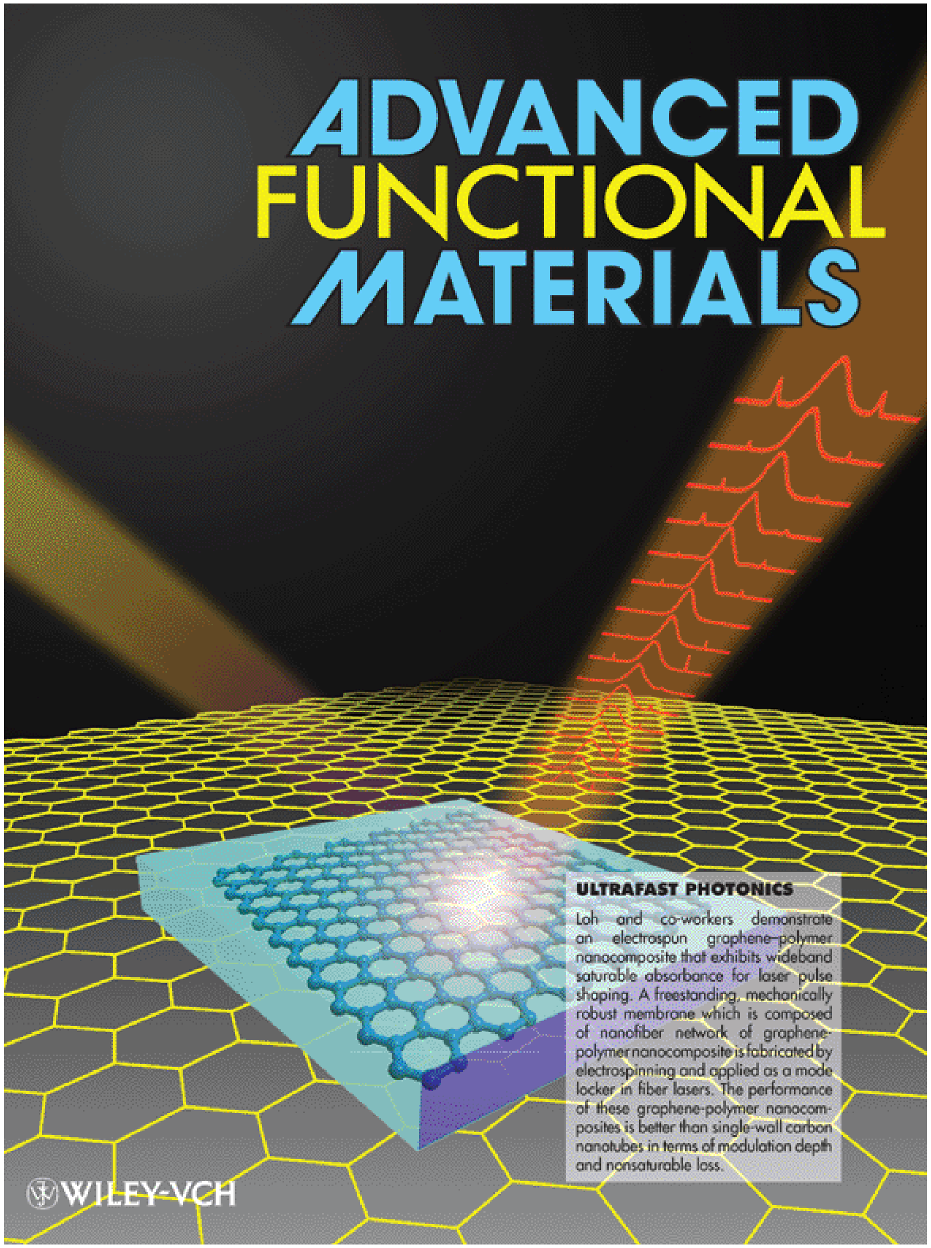
a mode-locking regime with the saturable absorbers based on CARBON NANOTUBES has been realized in a number of solid state lasers:



Graphene?





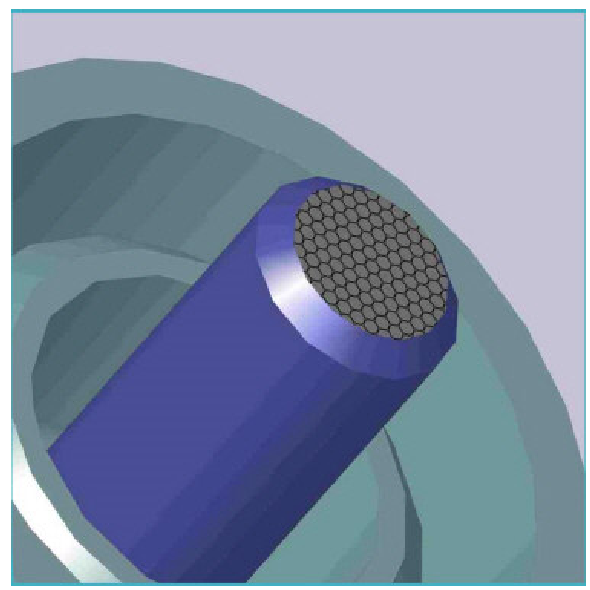


2009* – the first publications concerning mode locking with a *graphene saturable absorber

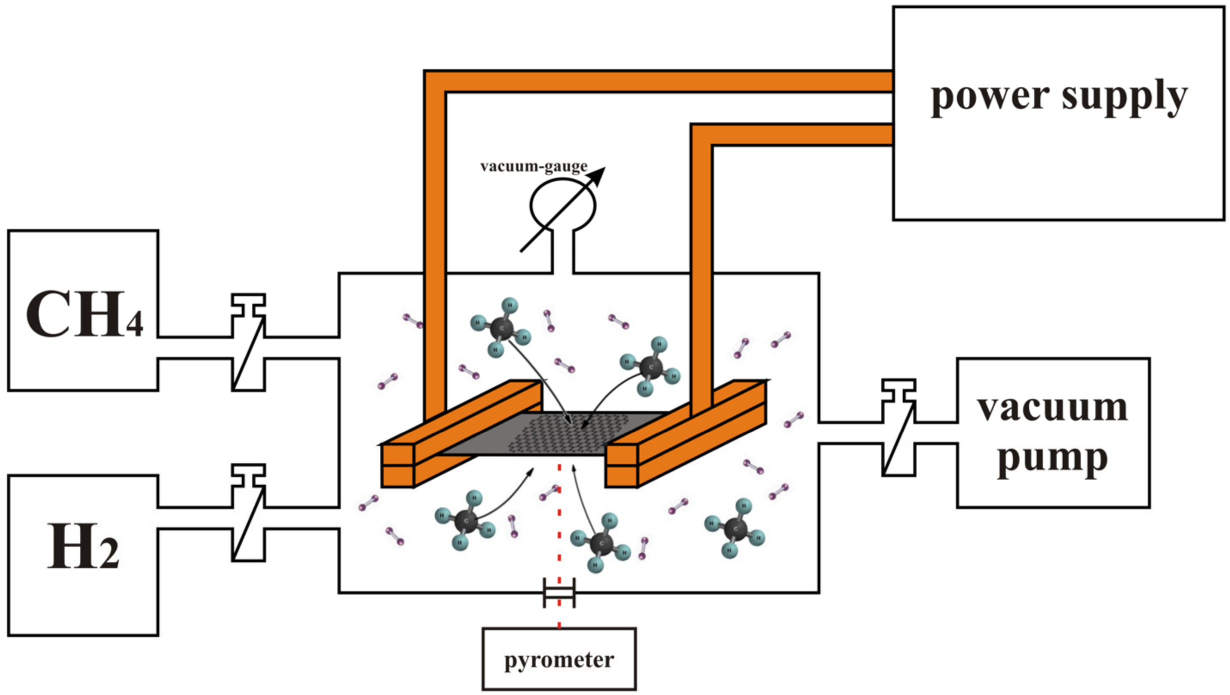
Q. Bao, H. Zhang et al. , Adv. Func. Materials 19 (2009) 3077.

T. Hasan, et al., Adv. Mater. 21 (2009) 3874.

http://nanotechweb.org/cws/article/tech/41949



A scheme of a home-made installation for CVD graphene synthesis

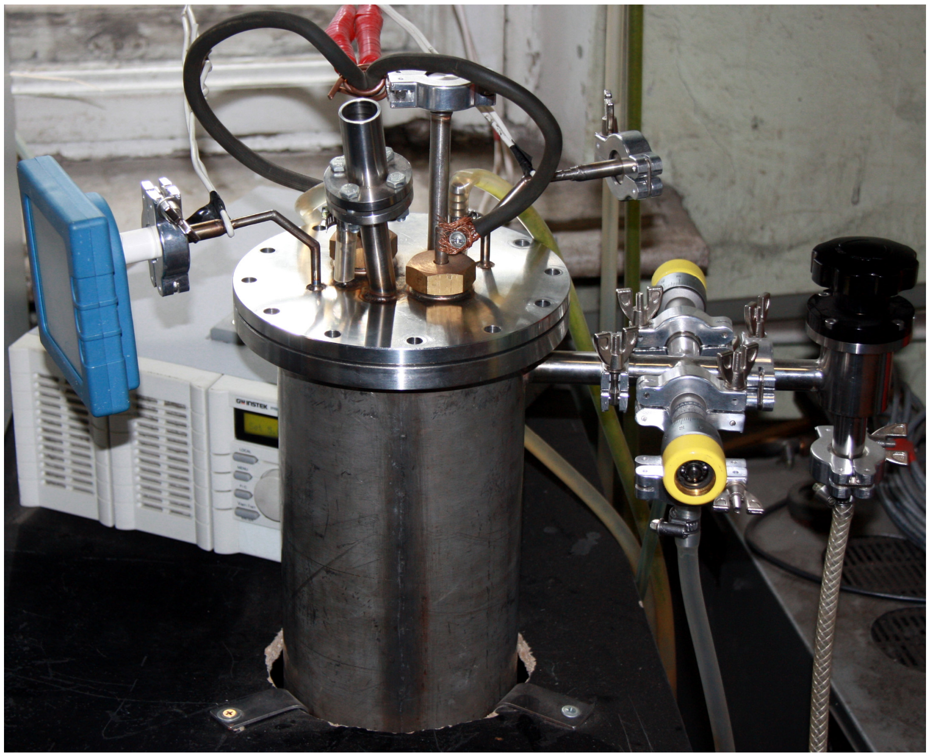


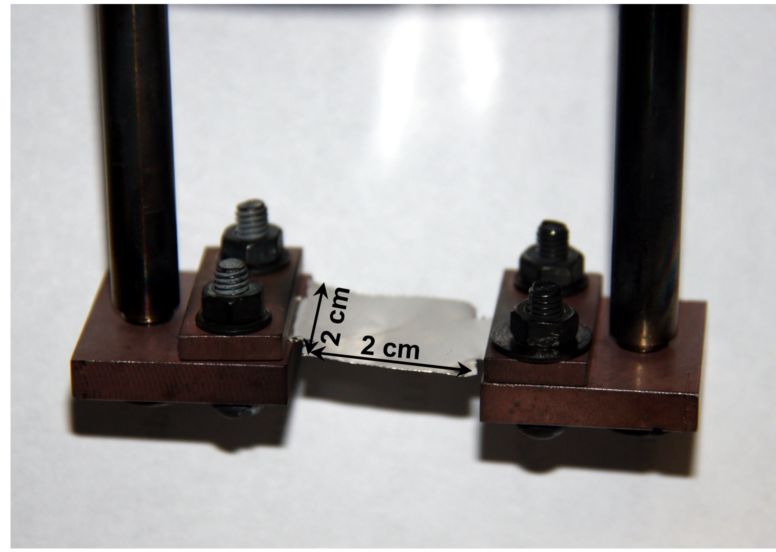
1. Pyrometer
2. An electric direct current source
3. Vacuum pump
4. Vacuum-gauge
5. CH_4 and H_2

The deposition temperature determines the number of layers!!!

Synthesis of graphene by CVD method

Home-made installation for chemical vapor deposition of graphene onto Ni foil heated by electrical current



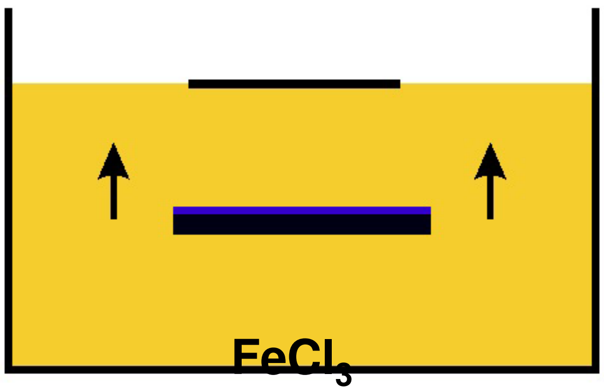


The nickel foil between two electrodes

The optimal size of the foil is 2x2 cm

M.G. Rybin, A.S. Pozharov and E.D. Obraztsova
"Control of number of graphene layers grown by chemical vapor deposition",
Phys. Status Solidi C, 7 (2010) 2785-2788

Etching of Ni in $FeCl_3$ and formation of **a free-standing graphene** film

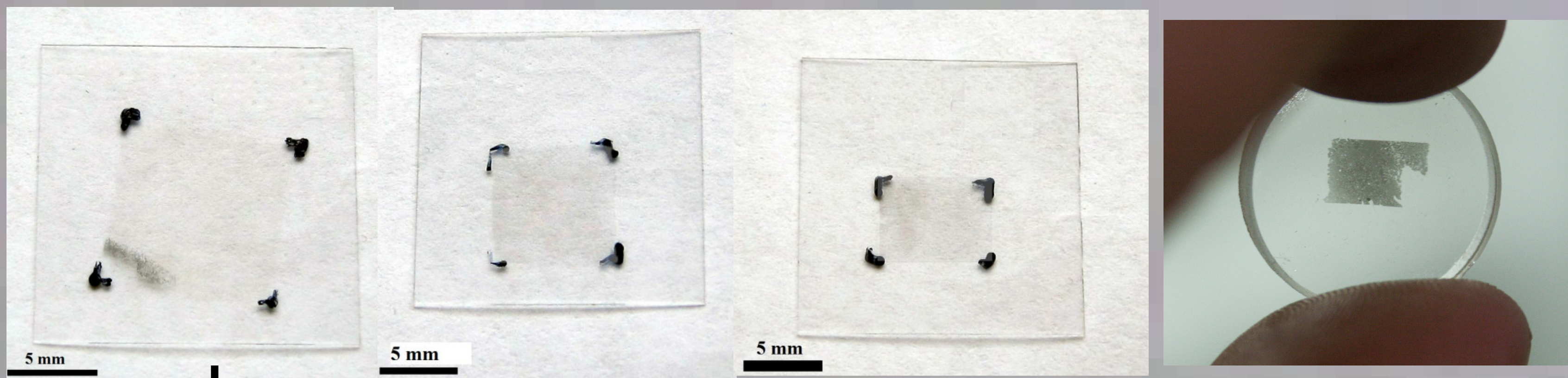


Graphene on Ni

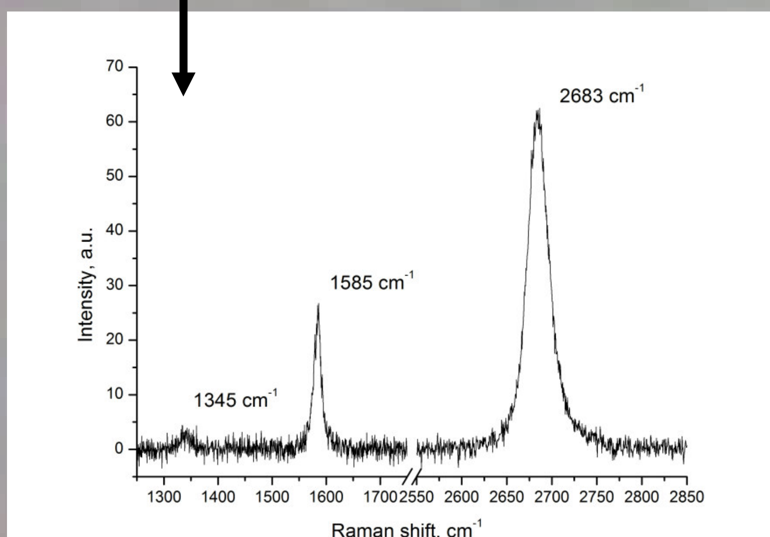
Graphene on the surface of $FeCl_3$ solution

Graphene on glass

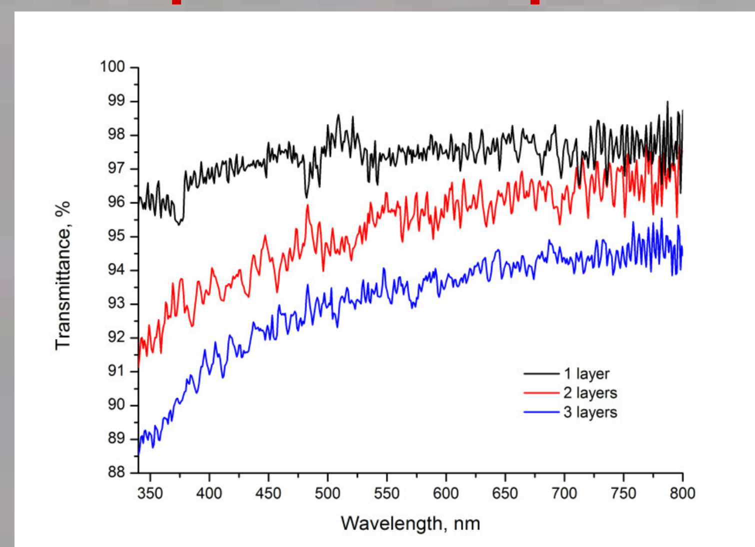
1 layer **2 layers** **3 layers** **20 layers**

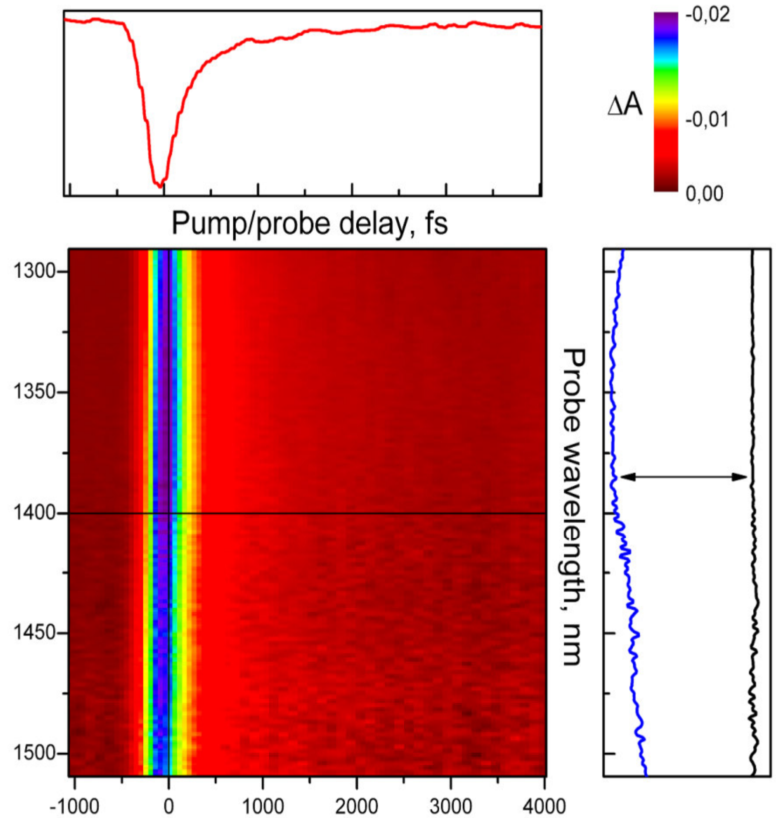


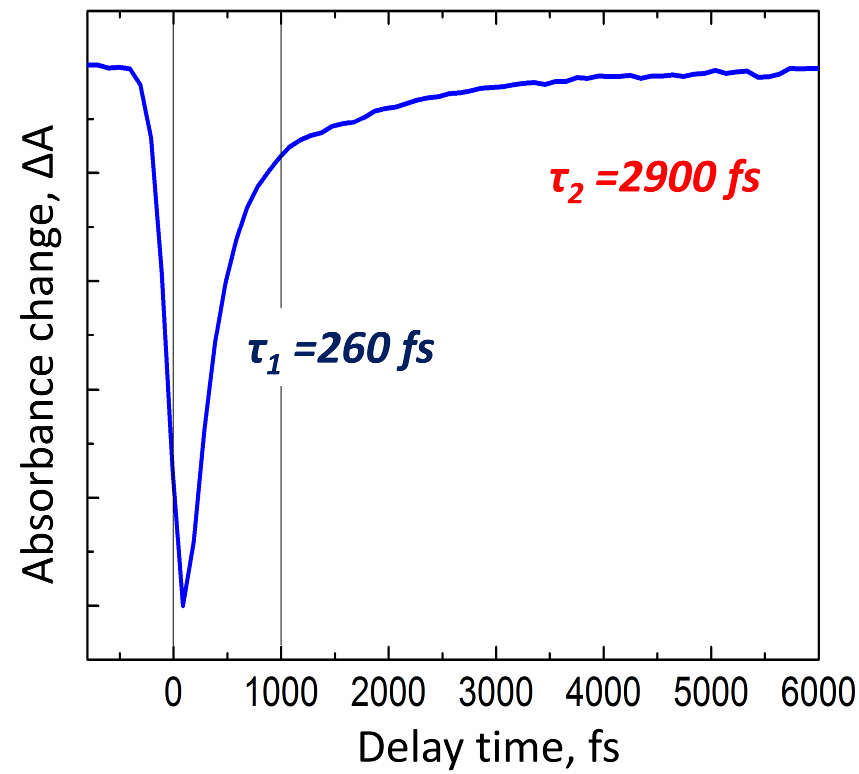
Raman



Optical absorption







P.A. Obraztsov et al.

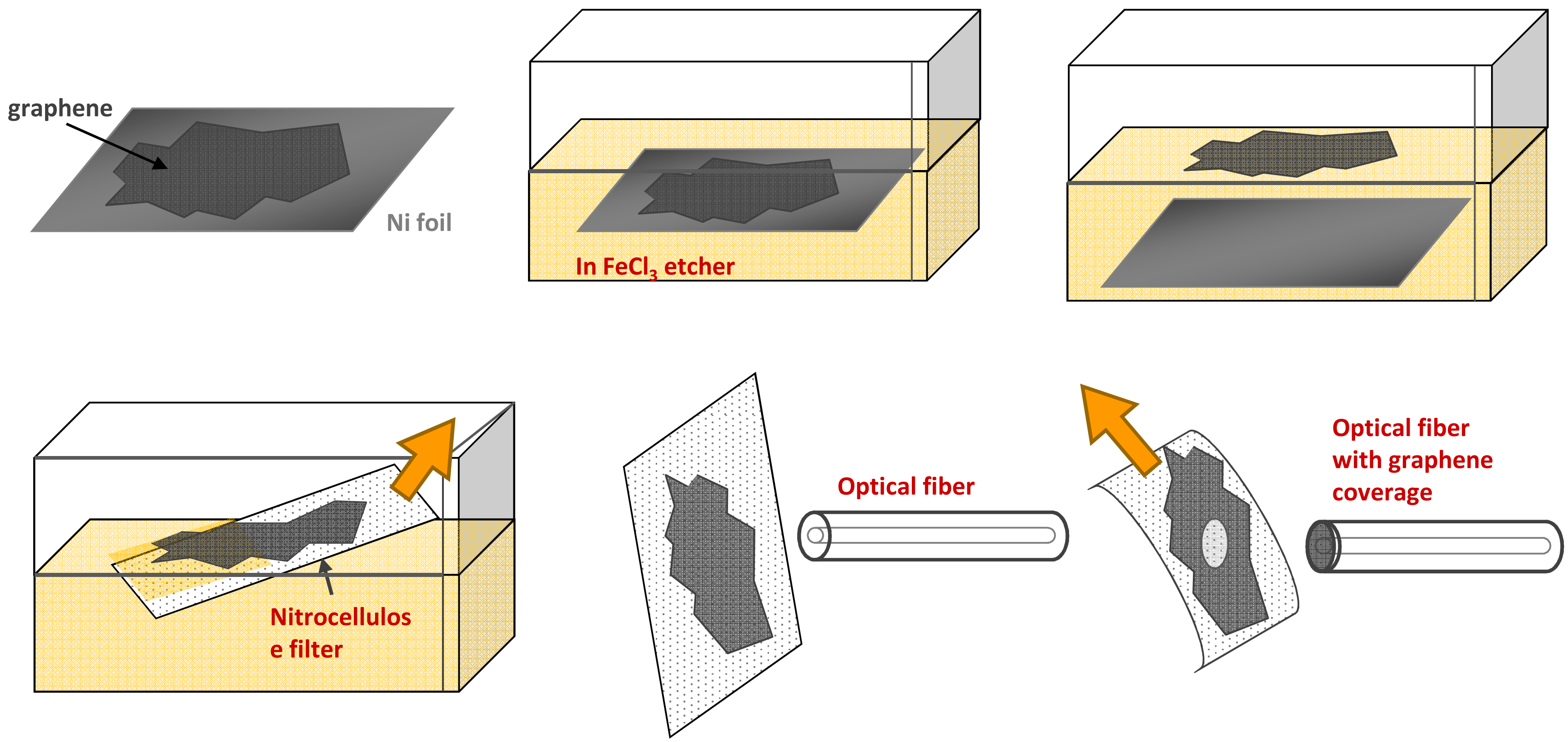
"Broadband Light-Induced Absorbance Change in Multilayer Graphene",

NanoLetters 11 (2011)1540.

Mode locking with graphene

1. Er fiber laser (1.55 μm)
2. CO_2 bulk laser (10 μm)

Reprinting the graphene film on the cross section of optical fiber



1- graphene film on Ni

2 – Etching in FeCl3

3- Separation of film and substrate

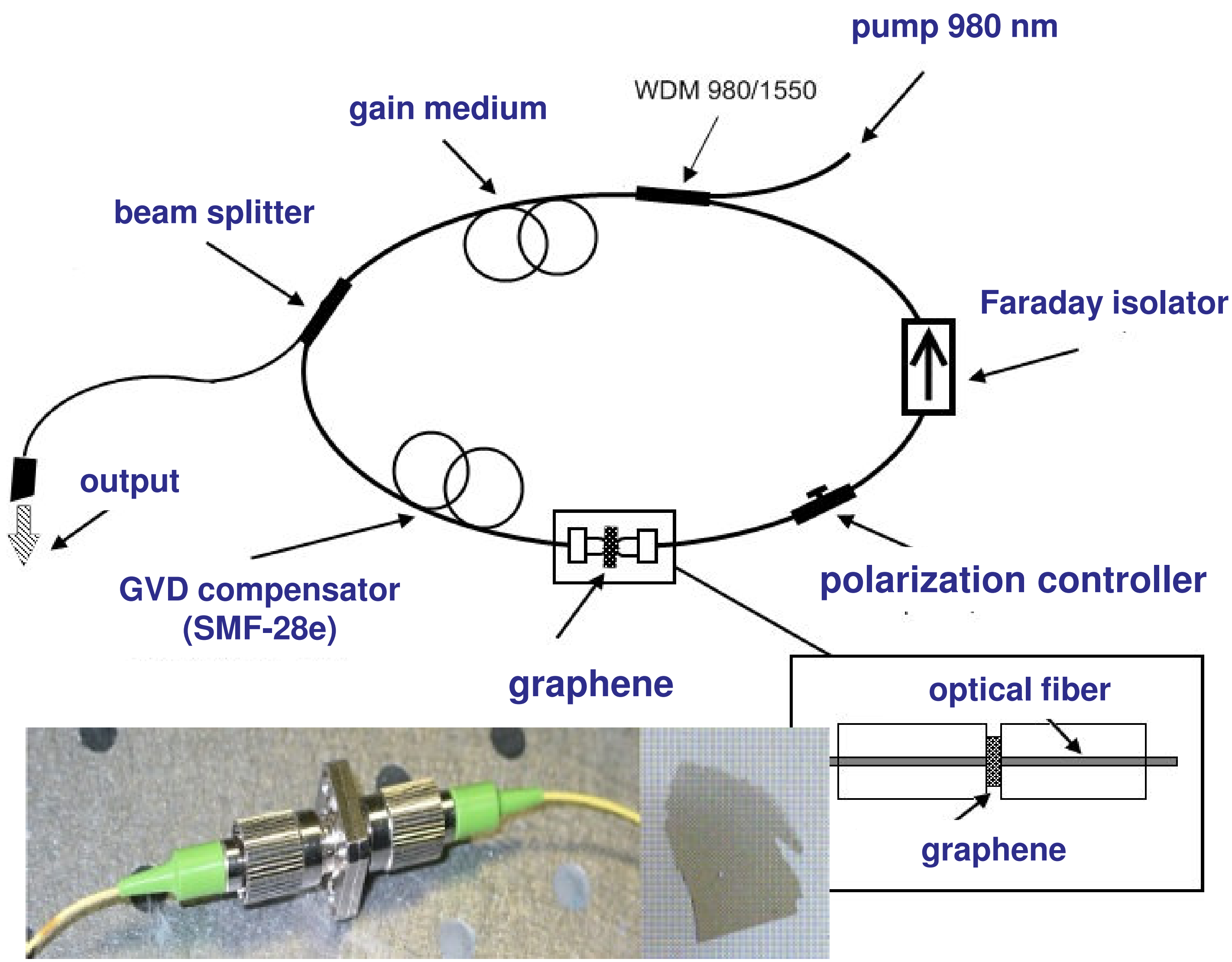
4 – Film fished out onto a nitrocellylose filter

5 – Pressing the filter to the fiber

6 – Graphene coverage onto the fiber cross-section

http://lem.onera.fr/download/lectures_graphene/Obraztsov/Obraztsova%20E_reduit.pd

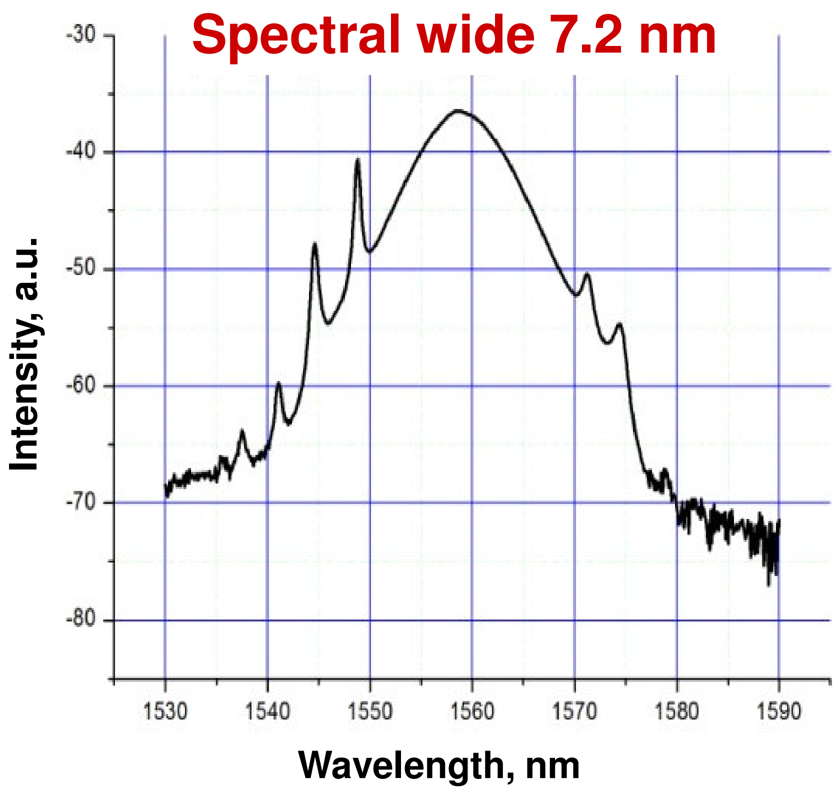
Cargese school on graphene (France), 2010.



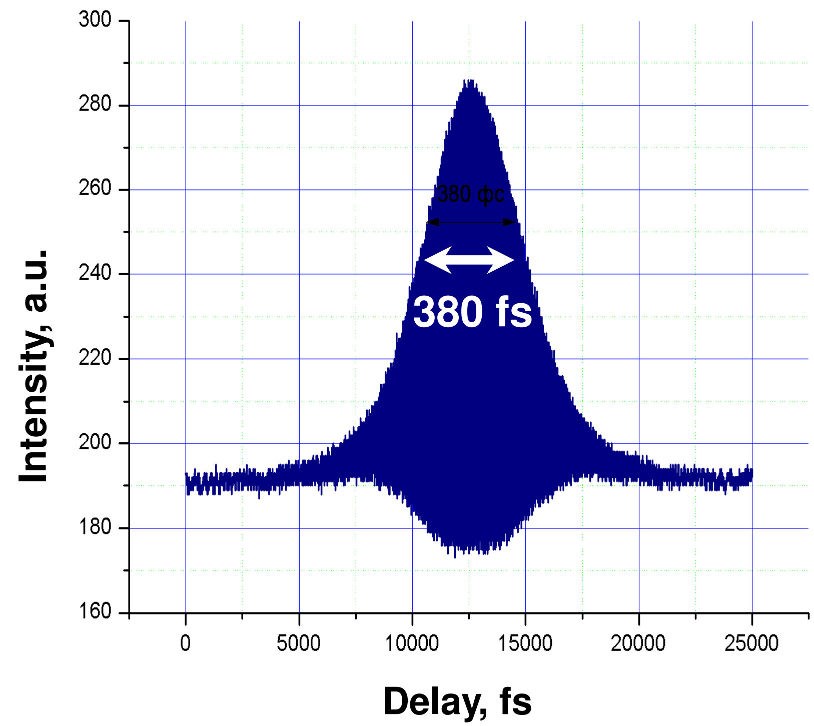
A scheme of Er fiber laser with a graphene saturable absorber

Generation of 380 fs pulses with the graphene saturable absorber

Output spectrum



Output autocorrelation function



PErL Femtosecond OEM Er Fiber Laser

PErL Femtosecond OEM Er Fiber Laser – the commercial product

as result of the collaboration between the laboratory and the "Avesta" company

Laser specification

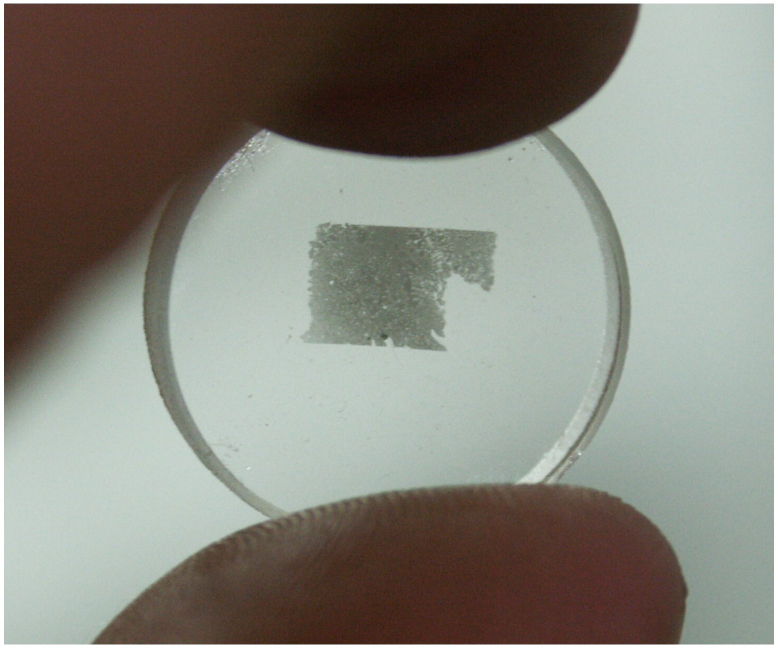
Available pulse duration (fixed), fs	250-5000
Wavelength, nm	1560±10
Average output power, mW	>50
Repetition rate, MHz	50
Output type	FC/APC fiber socket
Polarization extinction ratio, dB	not applicable
RF sync out	SMA connector (200-300 mV @ 50 ohm load)
Dimensions, mm	**136 x 76 x 24 (27)**
Power supply	+5 V

http://www.avesta.ru

A new spectral range

Graphene saturable absorbers for semi-industrial mid-IR CO and CO_2 lasers

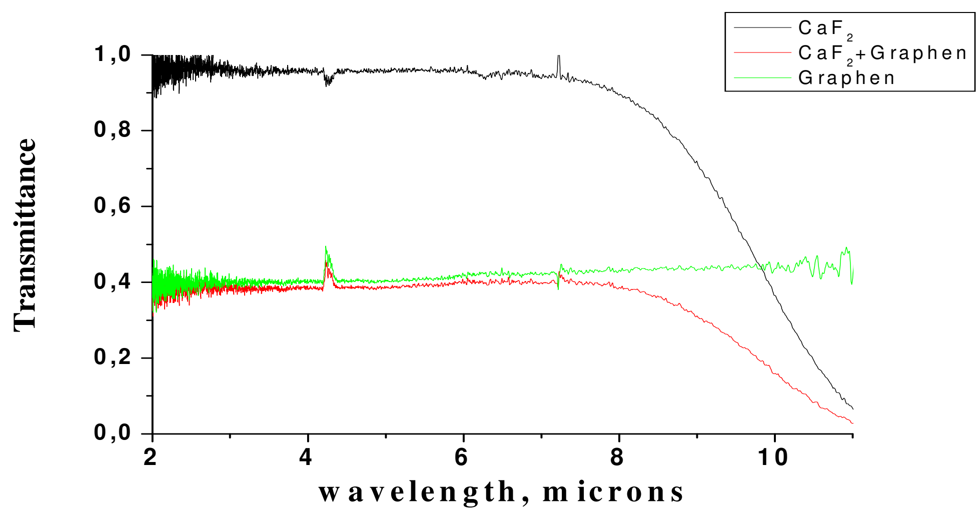
With Dr. Yu. Klimachev and Dr. V. Sorochenko



A 20-graphene layer saturable absorber deposited on CaF_2 for mode-locking in CO laser (4.7-7.0 μm)

For CO_2 laser (10 μm)

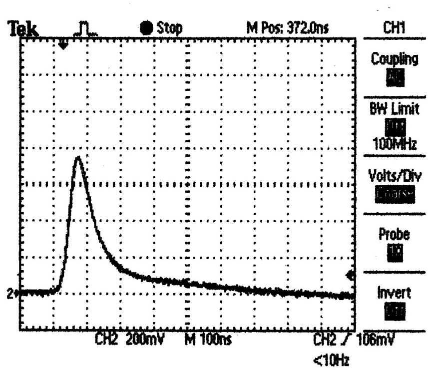
a BaF_2 substrate is used.

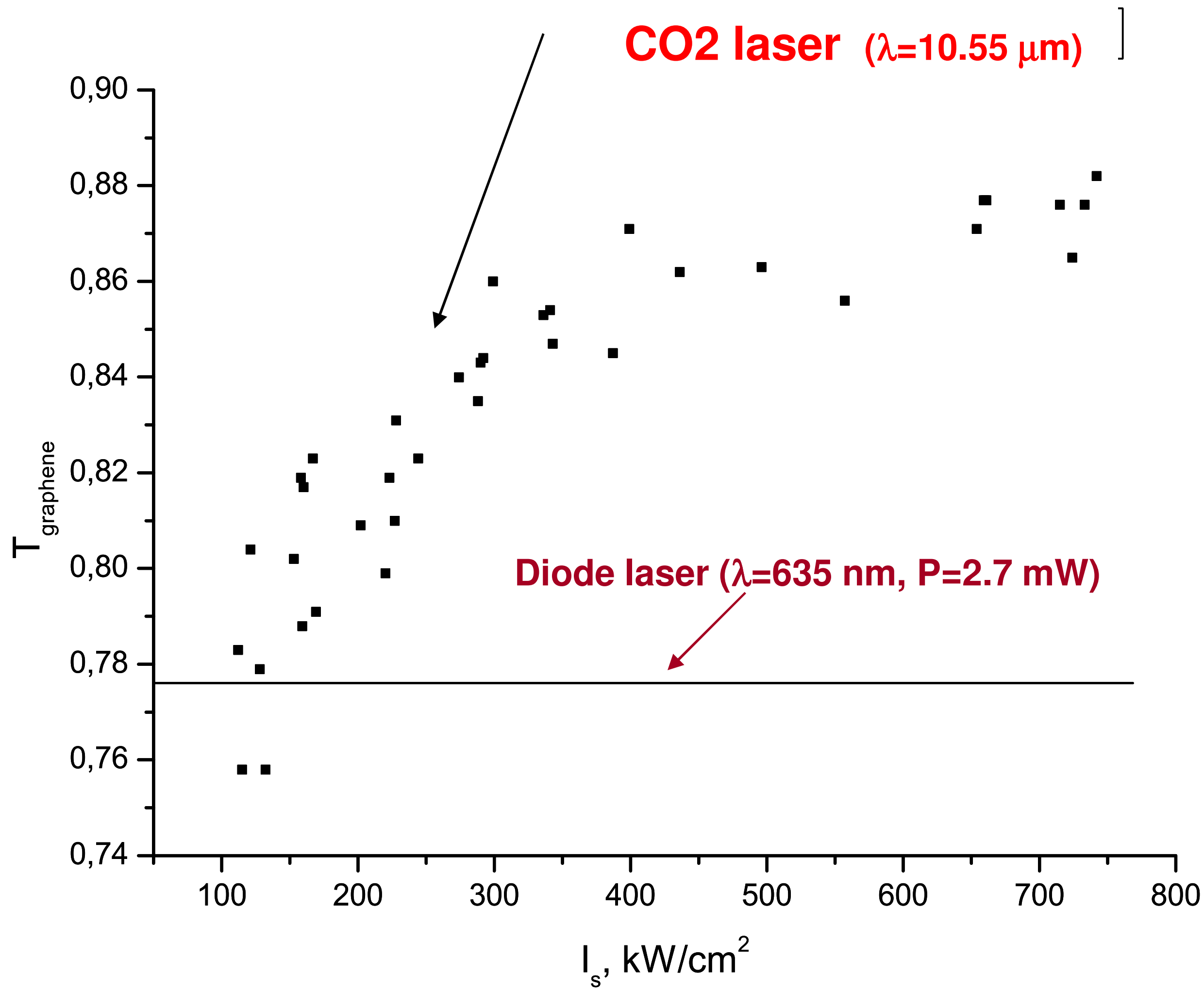


https://webistem.com/bin/pdfview?dir=gnt2011&level=2&ref=121

GNT-meeting, Dourdan (France) 2011.

Saturable absorption of a few layer graphene at wavelength 10.55 μm





Conclusion

Graphene has been demonstrated as a prospective material for
a new family of
ultrafast (sub-picosecond) and efficient saturable absorbers
working in a spectral range 1-12 mkm.

The work was supported by Russian research programs RFBR-10-02-00792 and "Nanomaterials and Nanotechnologies".