Bi-doped optical fibers and their potential applications

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Outline

- Why Bi-doped fibers?
- Luminescent properties of Bi-doped materials
- Nature of Bi NIR active centers
- Luminescence and optical losses of Bi-doped fibers with different compositions
- Bi-doped fiber lasers and their applications
- Conclusion

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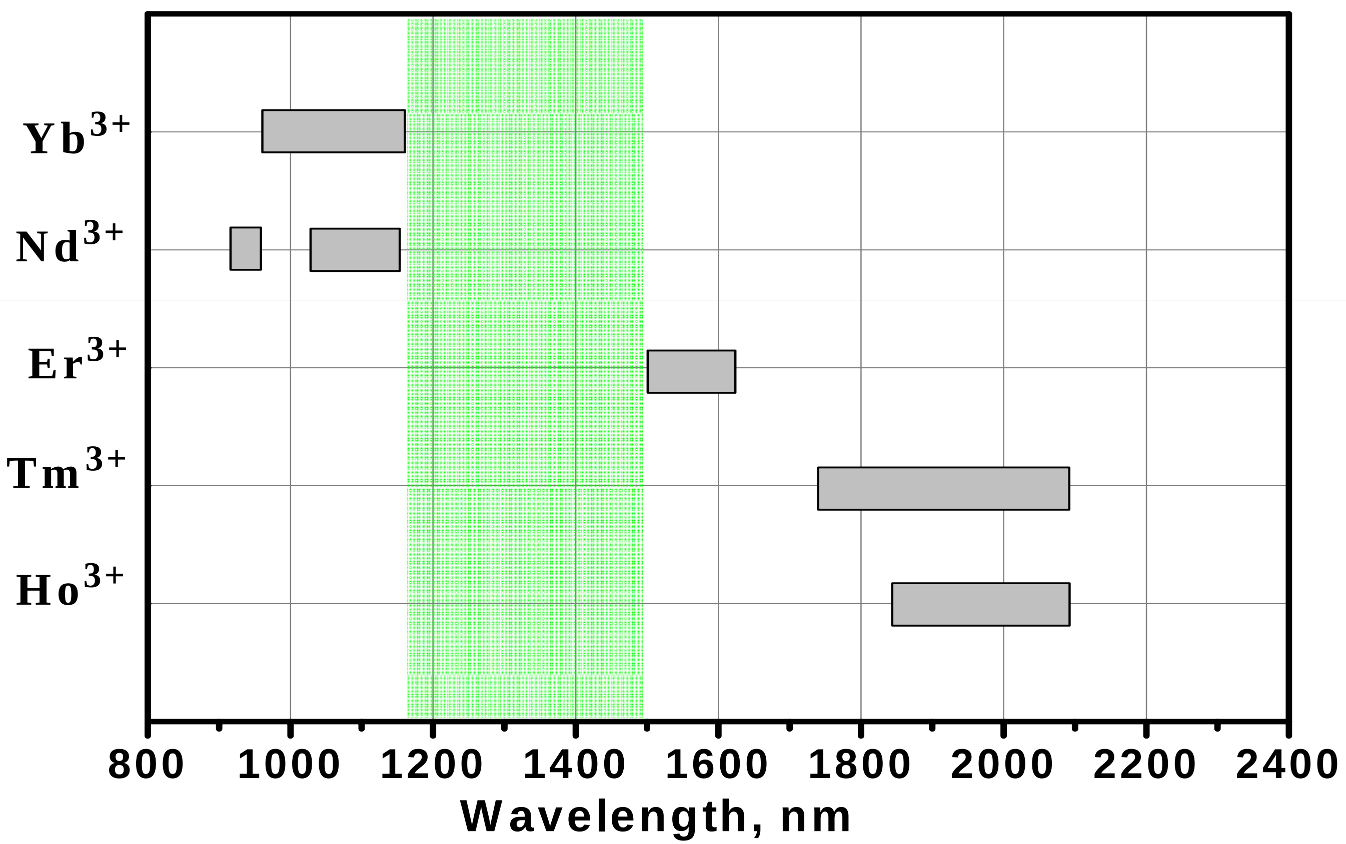
Spectral regions of the existing fiber lasers



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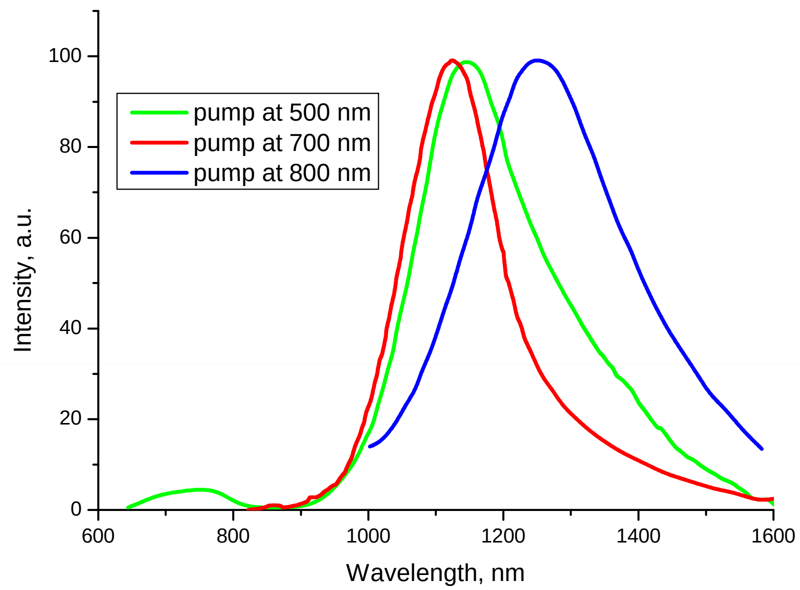
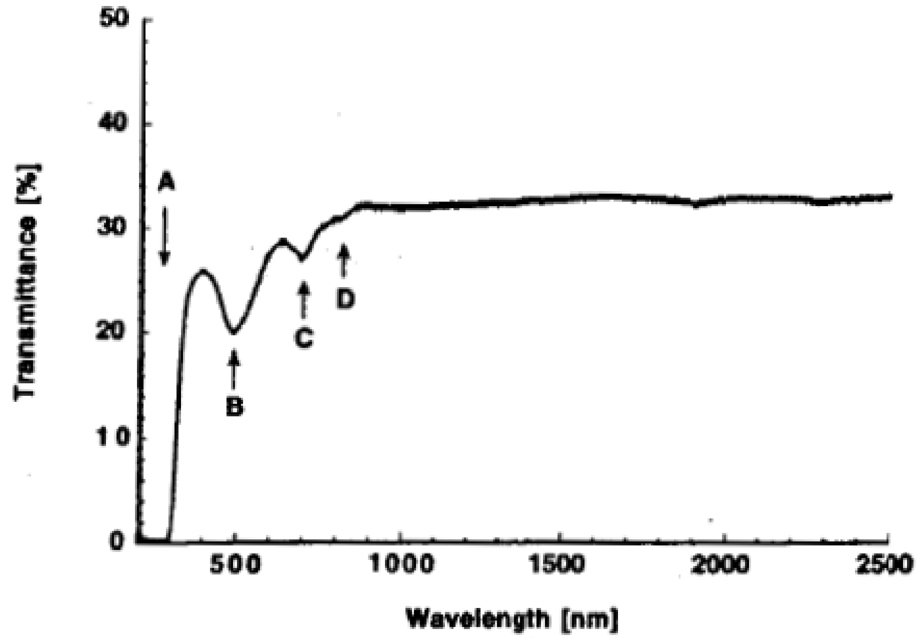
Transmission and luminescence spectra of Bi-doped silica glass (Fujimoto and Nakatsuka, 2001)





1. K. Murata, Y. Fujimoto, T. Kanabe, H. Fujita, M. Nakatsuka. Fusion Engineering and Design, **44**, 437 (1999).

2. Y. Fujimoto and M. Nakatsuka, Jpn. J. Appl. Phys, **40**, L279 (2001).

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Luminescence properties of various Bi-doped materials

N	Composition (mol%)	λp (nm)	λe (nm)	FWHM (nm)	τ (μs)	References
1	$96GeO_2 – 3Al_2O_3 – 1Bi_2O_3$	800	1300	320	255	M.Peng et al., 2004
2	$63SiO_2$-$23Al_2O_3$-$13Li_2O$-$1Bi_2O_3$	700 800 900 900	1100 1250 1100 1350	250 450 500	550	Suzuki and Ohishi, 2006
3	$50SiO_2$-$30GeO_2$-15MgO-$5Al_2O_3$-$1Bi_2O_3$	808 980	1280 1155	355 250		J.Ren et al., 2007
4	$65P_2O_5$-$12B_2O_3$-$7La_2O_3$-$6Al_2O_3$-$9Li_2O$-$1Bi_2O_3$	530 800 980	690 1150 1270 1125	100 290	4 220 290	B.Denker et al., 2007
5	$70GeS_2$-$9.5Ga_2S_3$- 20KBr-$0.5Bi_2O_3$	808	1230			G.Yang et al., 2007
6	$RbPb_2Cl_5$:Bi crystal	633 808 919	1080	~150	140	A. Okhrimchuk et al., 2008
7	55.6 SiO_2 -22.2MgO-$22.2Al_2O_3$-XBi_2O_3 (X=0.25-2)	500 700 800	1160 1125 1270	~150	350-500 300-800	B.Denker et al., 2009

• λp, λe – pump and emission peak wavelengths, τ – lifetime of Bi luminescence.

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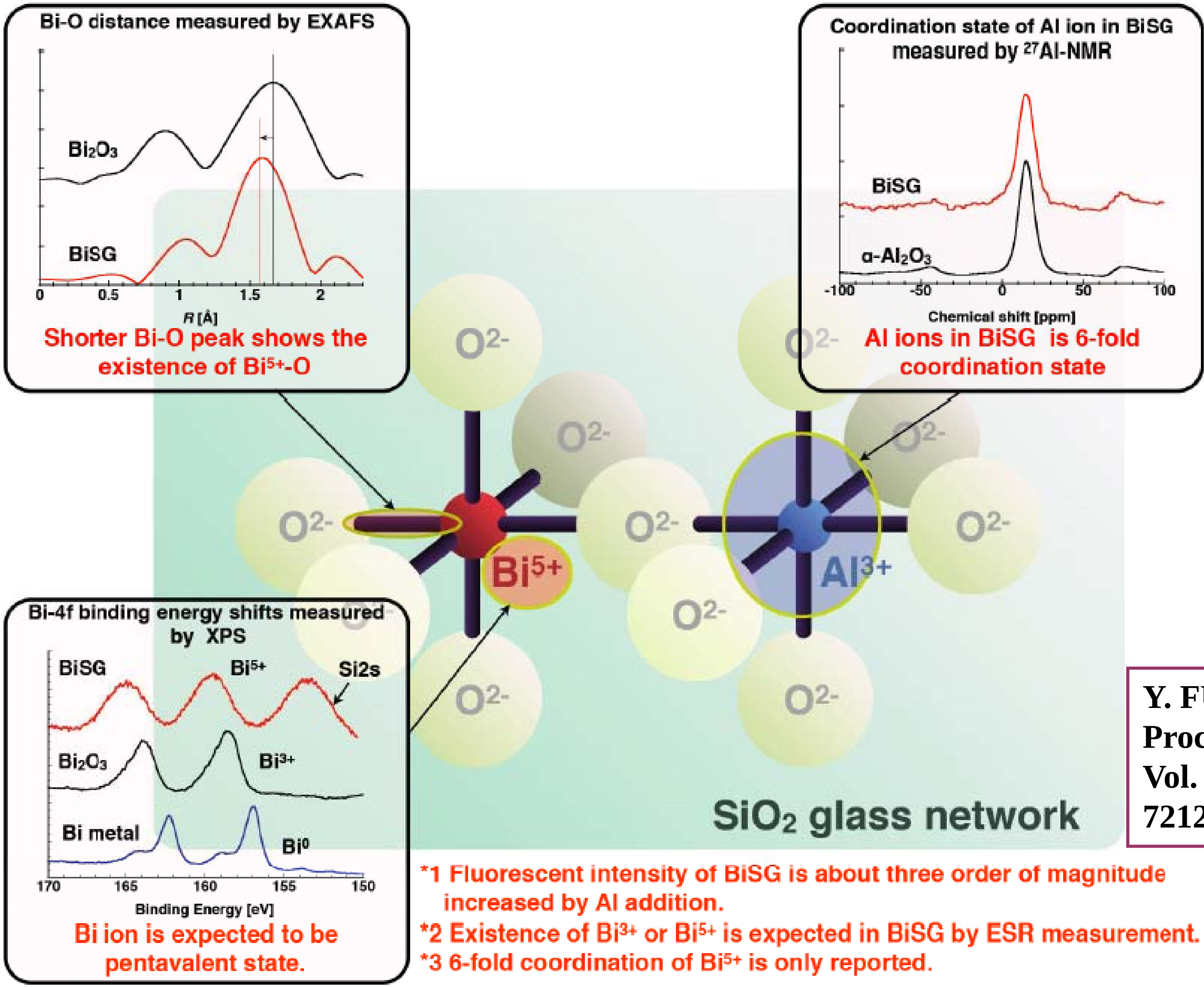
The expected local structure of Bi ion in BiSG



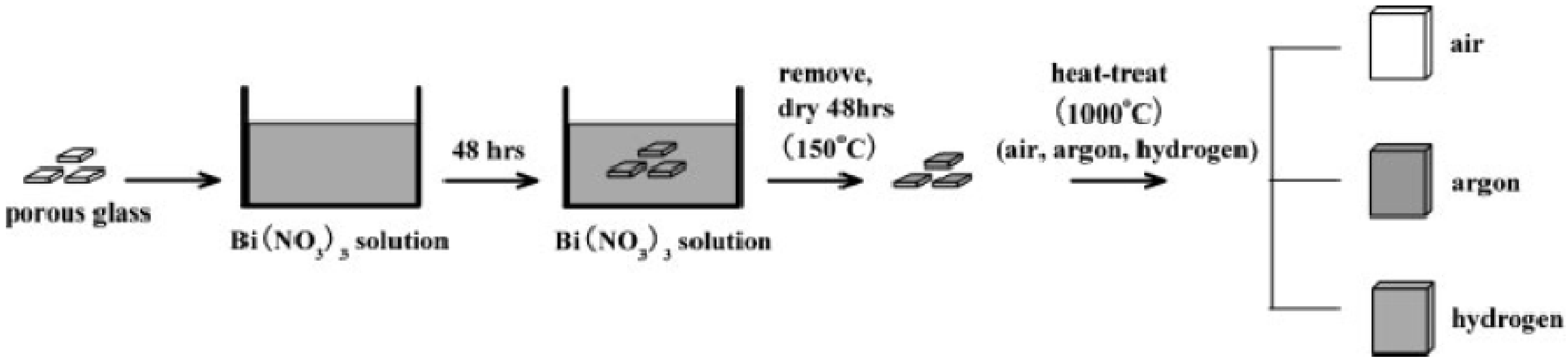
Y. FUJIMOTO
Proc. of SPIE
Vol. 7212
721202-2

*1 Fluorescent intensity of BiSG is about three order of magnitude increased by Al addition.

*2 Existence of Bi^{3+} or Bi^{5+} is expected in BiSG by ESR measurement.

*3 6-fold coordination of Bi^{5+} is only reported.

Sh.Zhou et al, Bi-doped Nanoporous Silica Glass, Adv. Funct. Mater., 18, 1407, 2008



glass A (air) λ_p=280nm, λ_e=465nm (Bi^{3+})

glass B (argon) λ_p=280nm, λ_e=465nm (Bi^{3+})
λ_p=483nm, λ_e=590nm (Bi^{2+})
λ_p=532nm, 980nm, λ_e=1100nm (Bi^{+}?)
λ_p=800nm, λ_e=1400nm (Bi^{+}?)

glass C (hidrogen) no emission

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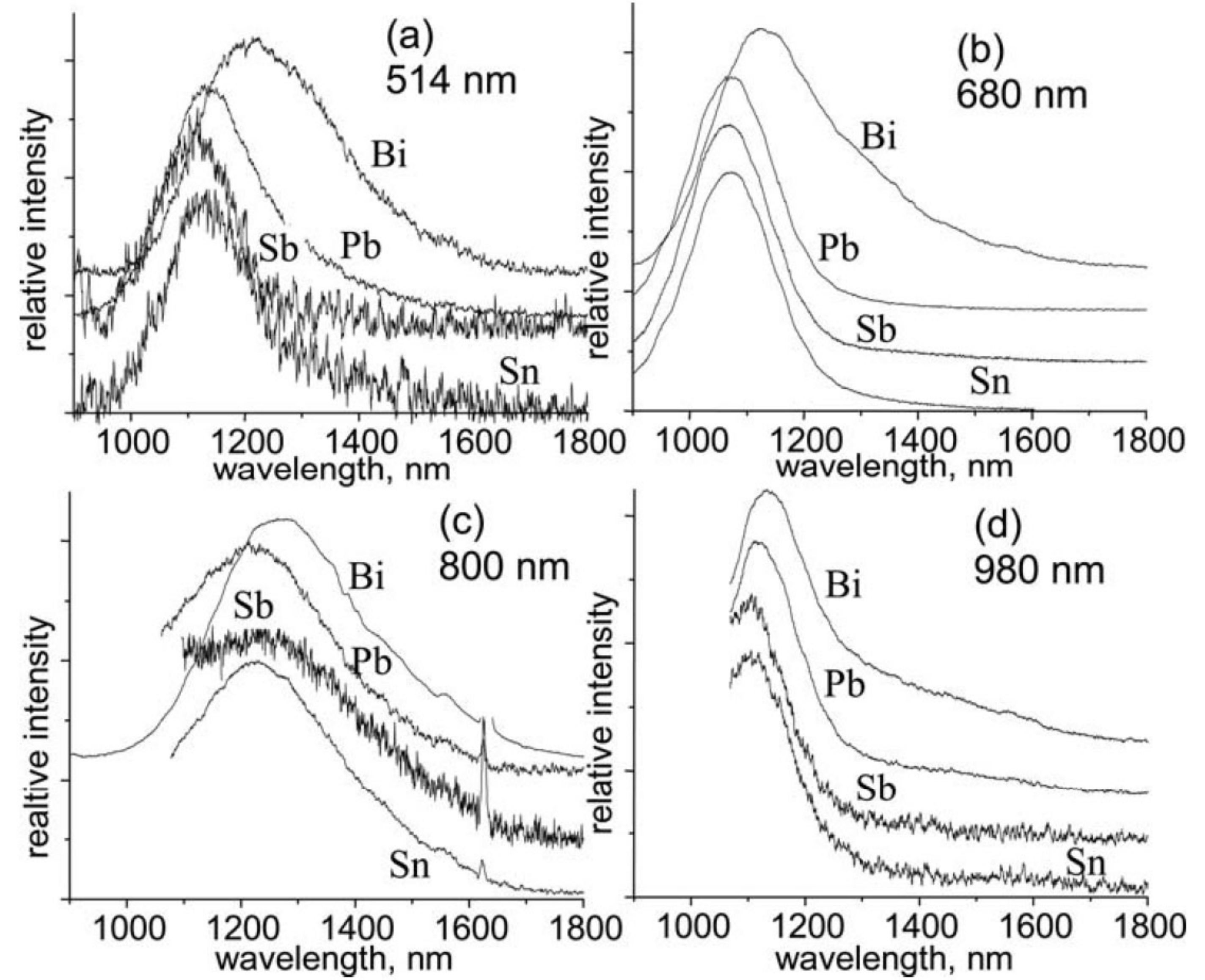

Fluorescence spectra are vertically shifted for clarity; fluorescence intensity is about zero at 1800 nm for all samples.

M.Yu. Sharonov et al. „Spectroscopic study of optical centers formed in Bi-, Pb-, Sb-, Sn-, Te-, and In-doped germinate glasses“, Opt. Lett., vol. 33, pp. 2131-2133, 2008

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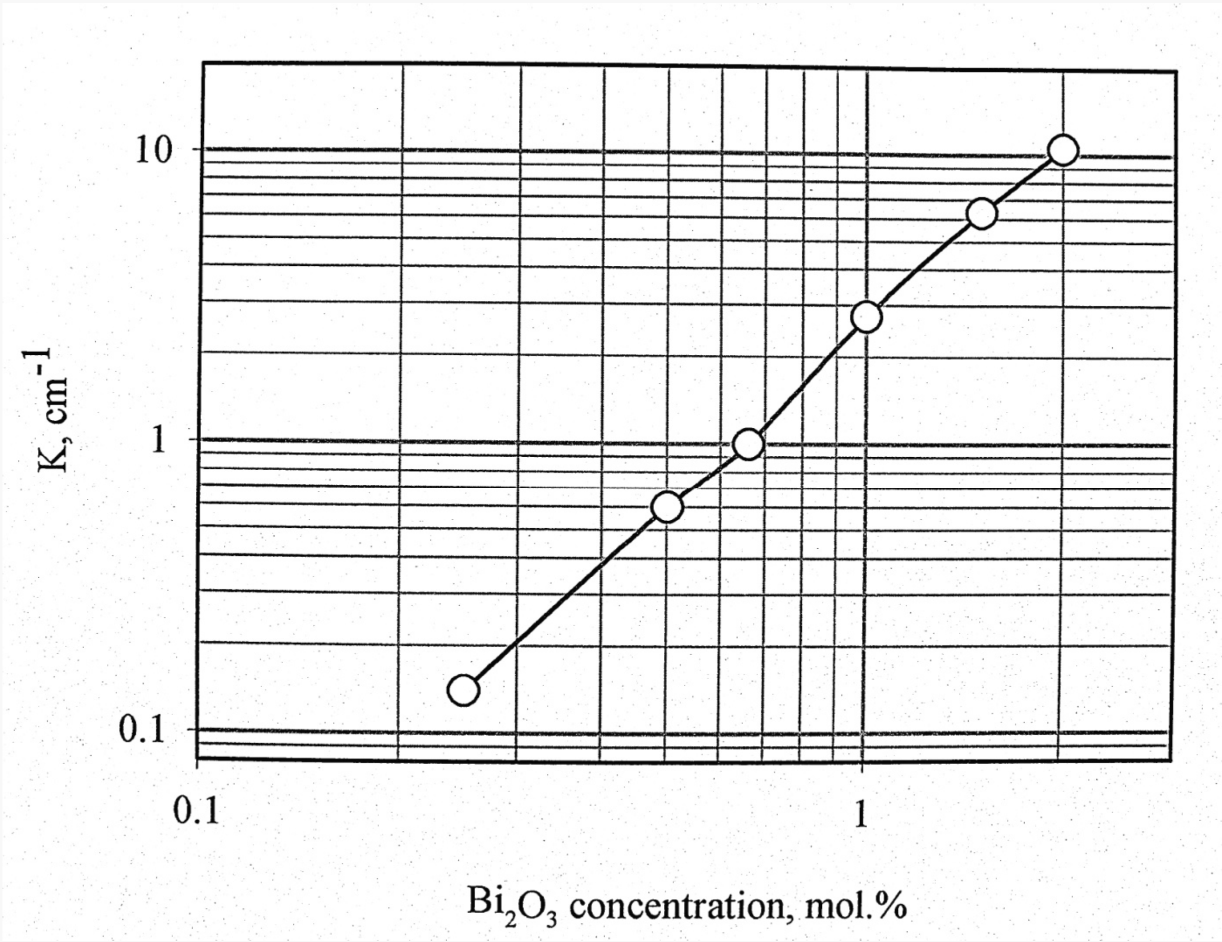
Extinction coefficient of Mg-Al-Si glass at the peak wavelength 500 nm versus Bi_2O_3 concentration



B.Denker et al., "Absorption and emission properties of Bi-doped Mg-Al-Si oxide glass system", Appl. Phys. Lett., (2009).

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What is a nature of Bi-related centers emitting in near IR?

- Bi^{5+} - Fujimoto and Nakatsuka, 2001
- Bi^{+} - X. Meng et al., 2005, Sh.Zhou et al. 2008
- BiO – J. Ren et al., 2006
- Bi_2, Bi_2^{-}, Bi_2^{2-} - Khonthon et al., 2007; Sokolov et al., 2008, Denker et al., 2009
- Point defects in glass – Sharonov et al., 2008, Lakshminarayana et al., 2009

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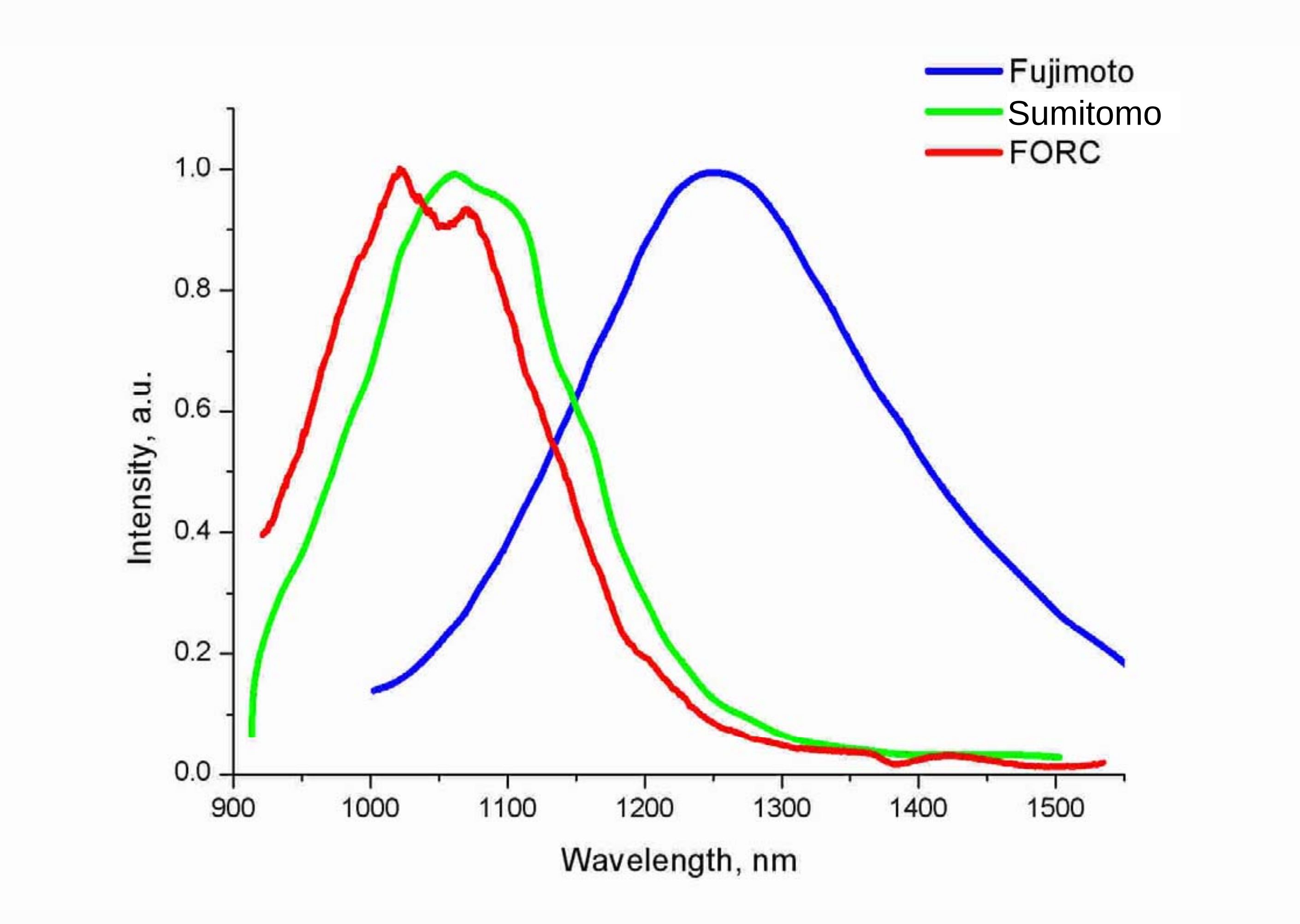
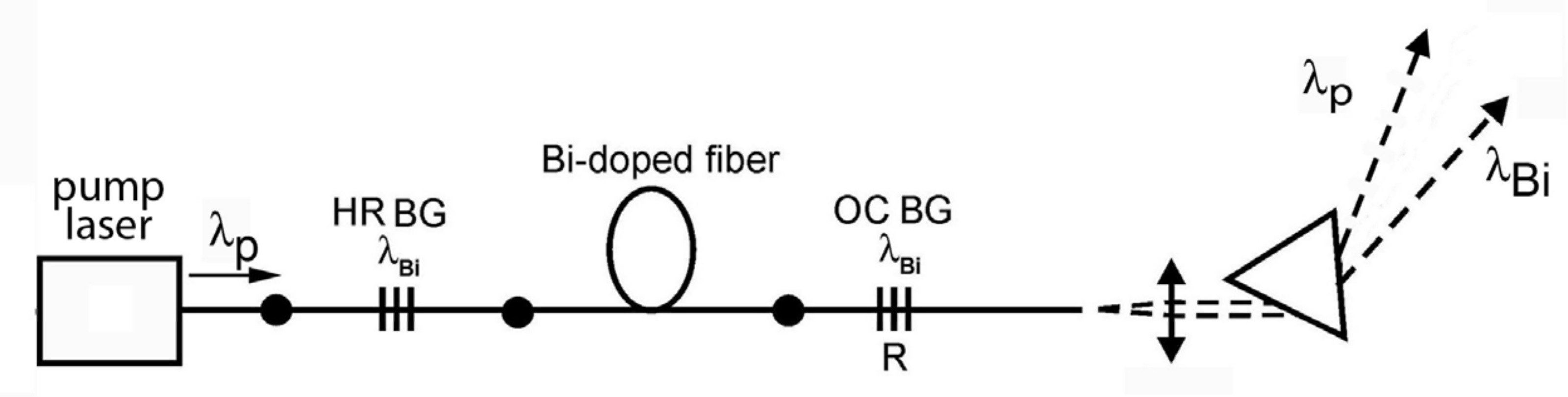
Luminescence spectra of Bi-doped silica glass (Fujimoto et al., 2001) and MCVD fibers (Sumitomo, FORC, 2005) pumped at 800 nm.



Bi-doped fiber lasers (1140-1215 nm) based on alumosilicate fibers

1. E.M.Dianov et al. “CW bismuth fiber laser”, Quant. Electron. 2005;
2. E.M.Dianov et al. “Yellow frequency-doubled bismuth fiber laser”, ECOC’2006
3. V.V.Dvoyrin et al. “Yb-Bi pulsed fiber laser”, Opt.Lett., 2007.
4. A.A.Krylov et al., “A mode-locked Bi-doped fiber laser”, OFC’2007.
5. E.M.Dianov et al. “High-power CW bismuth fiber laser”, JOSA B, 2007.
6. I.Razdobreev et al. “Efficient all-fiber bismuth-doped fiber laser”, Appl. Phys. Lett., 2007
7. A.B.Rulkov et al. “Narrow-line 1178 nm CW bismuth –doped fiber laser with 6.4 W output for direct frequency doubling”, Opt. Express, 2007.
8. V.V.Dvoyrin et al. “Effective Bi fiber lasers”, IEEE J.QE, 2008.
9. S. Yoo et al., “Bismuth-doped Fiber laser at 1.16 μm”, CLEO/QELS’2008.
10. I.A.Bufetov and E.M.Dianov, “Bi-doped fiber lasers”, Laser Physics Letters, 2009.
11. S.Kivistö et al., “Mode-locked Bi-doped all-fiber laser with chirped fiber Bragg grating”, IEEE Photon. Technol. Lett., 2009.

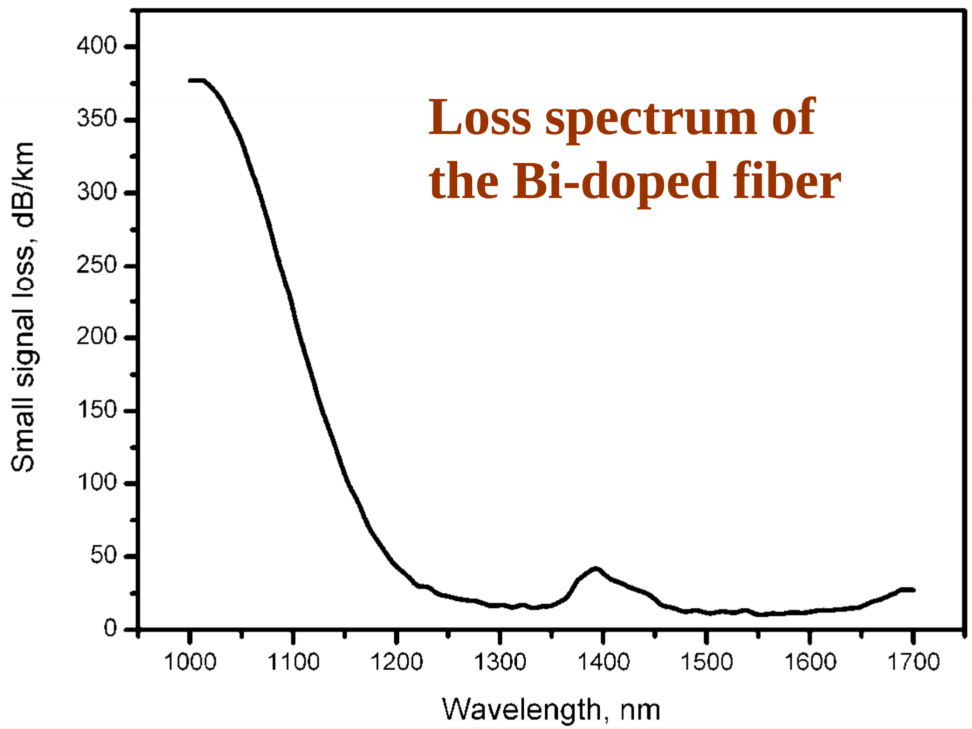
Scheme of a CW Bi-doped fiber laser



L=50-80 m, λ_p=1070 nm,

$\alpha \cong 0.3$dB/m

$C_{Bi} \leq 2 \cdot 10^{-2}$ at%



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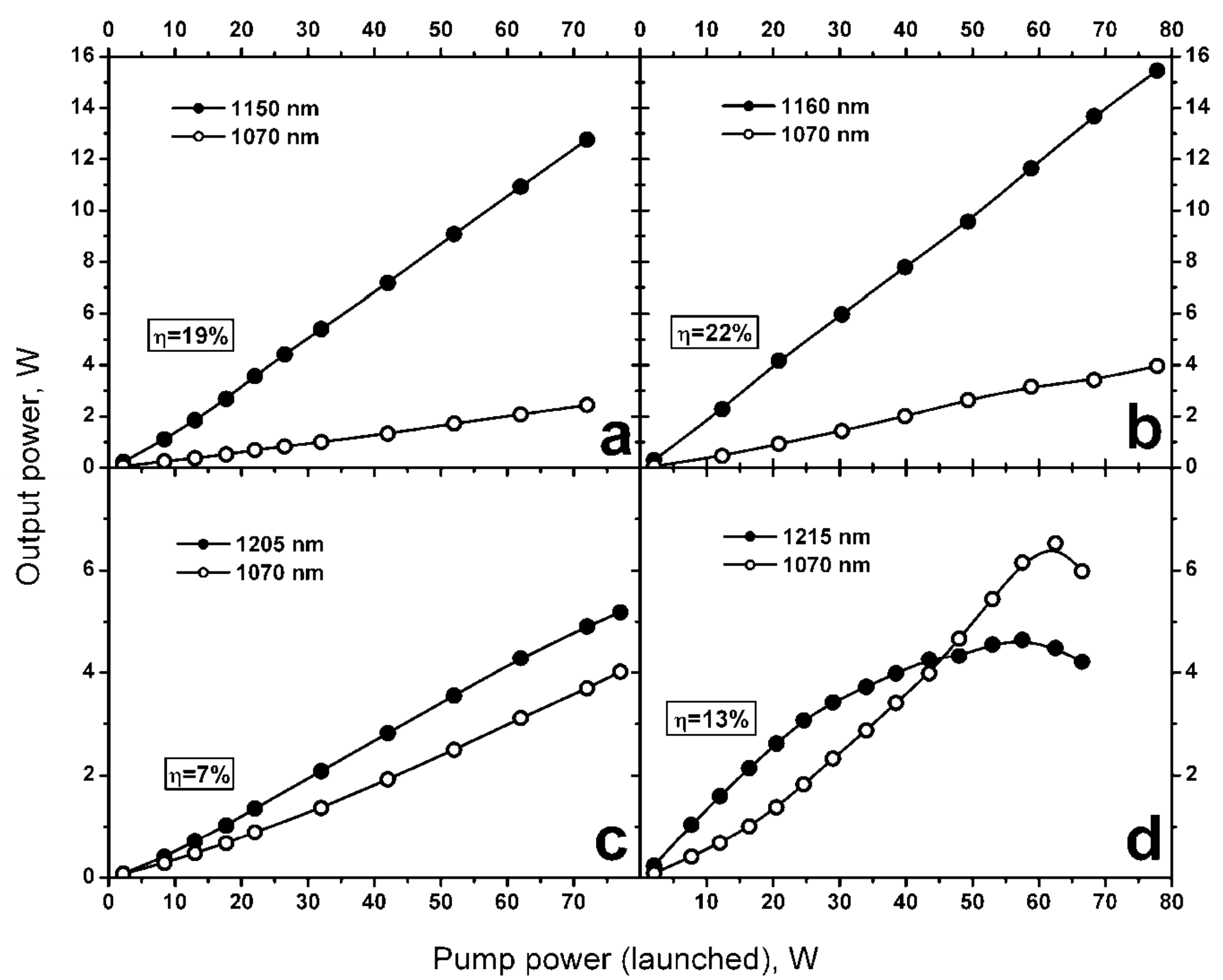
Output power for various laser wavelengths vs launched pump power at λ_p=1070 nm (room temperature)



E.M.Dianov, A.V.Shubin, M.A.Melkumov, O.I.Medvedkov, I.A.Bufetov, JOSA B, 2007.

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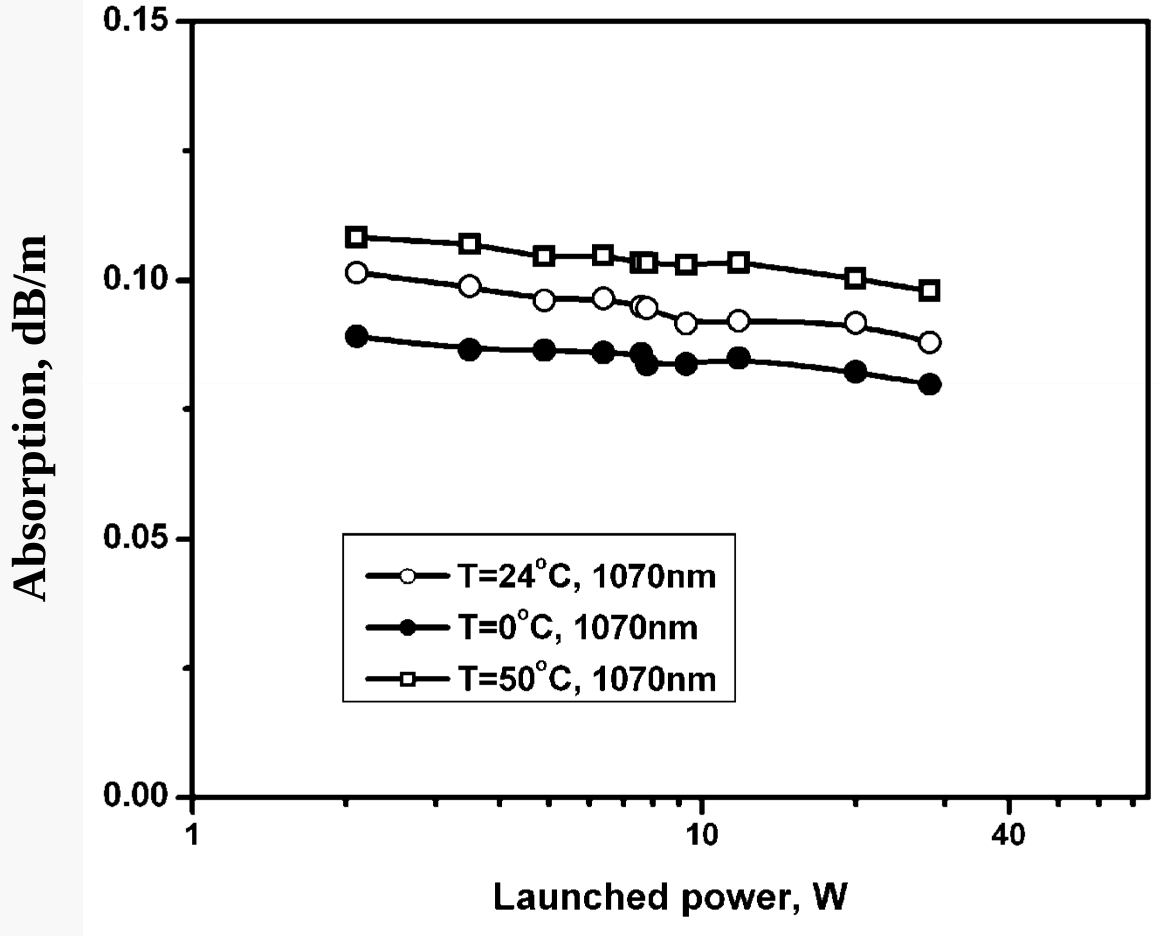
Optical losses of the Bi-doped fiber vs launched power at different temperatures



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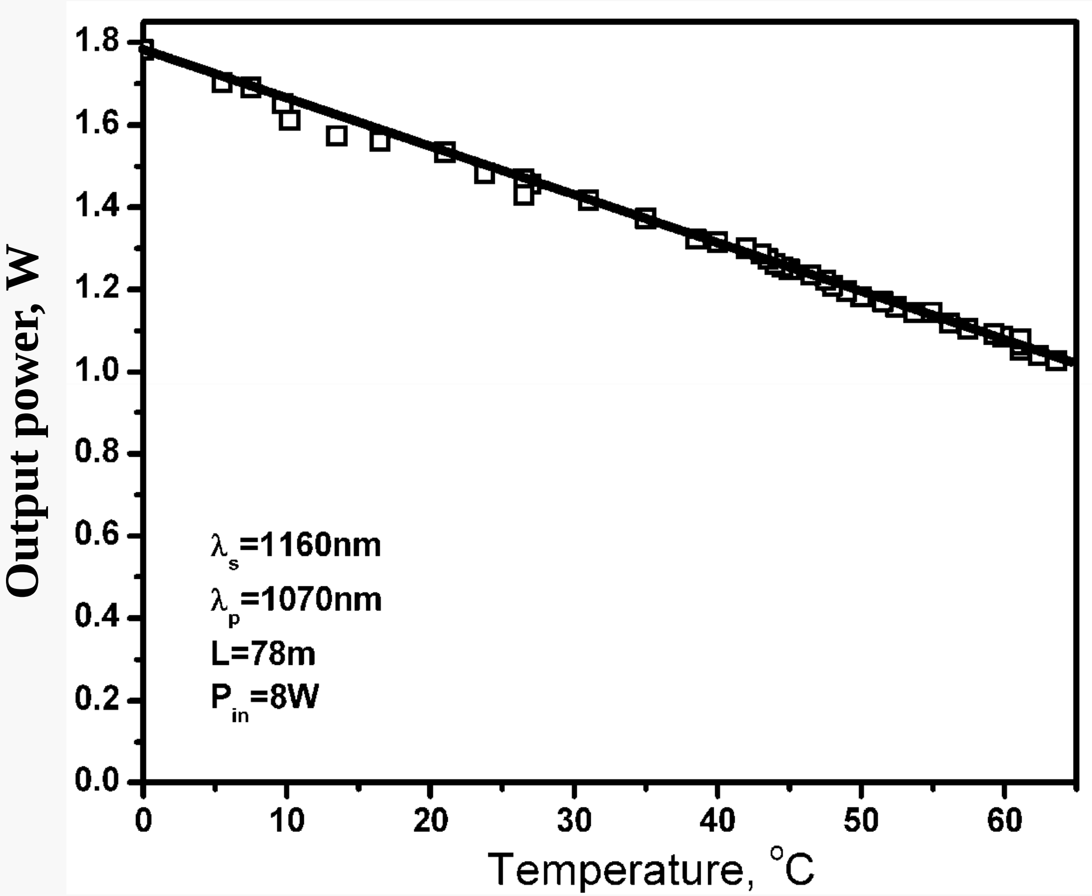
Output power of the Bi-doped fiber laser vs the fiber temperature at the pump power of 8W



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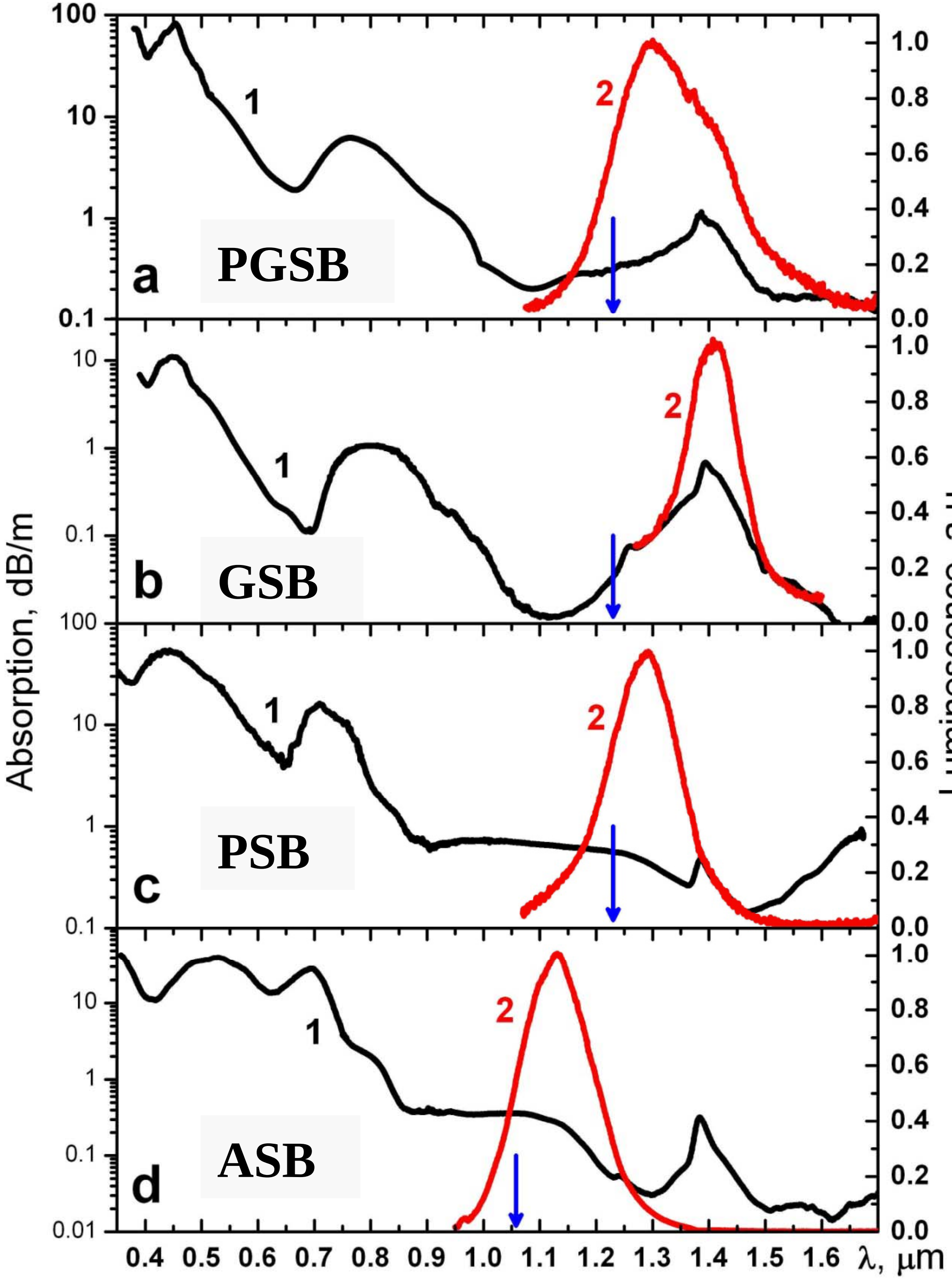

	mark	Core glass composition, (concentration in mol.%,)
a	PGSB	$83.5SiO_2$-$1.5P_2O_5$-$15GeO_2$
b	GSB	$85SiO_2$-$15GeO_2$
c	PSB	$92.5SiO_2$-$7.5P_2O_5$
d	ASB	$97SiO_2$-$3Al_2O_3$

Optical losses (**1**) and **luminescence spectra** (**2**) of PGSB, PSB, GSB, ASB fibers

Vertical arrows indicate the pump wavelengths.

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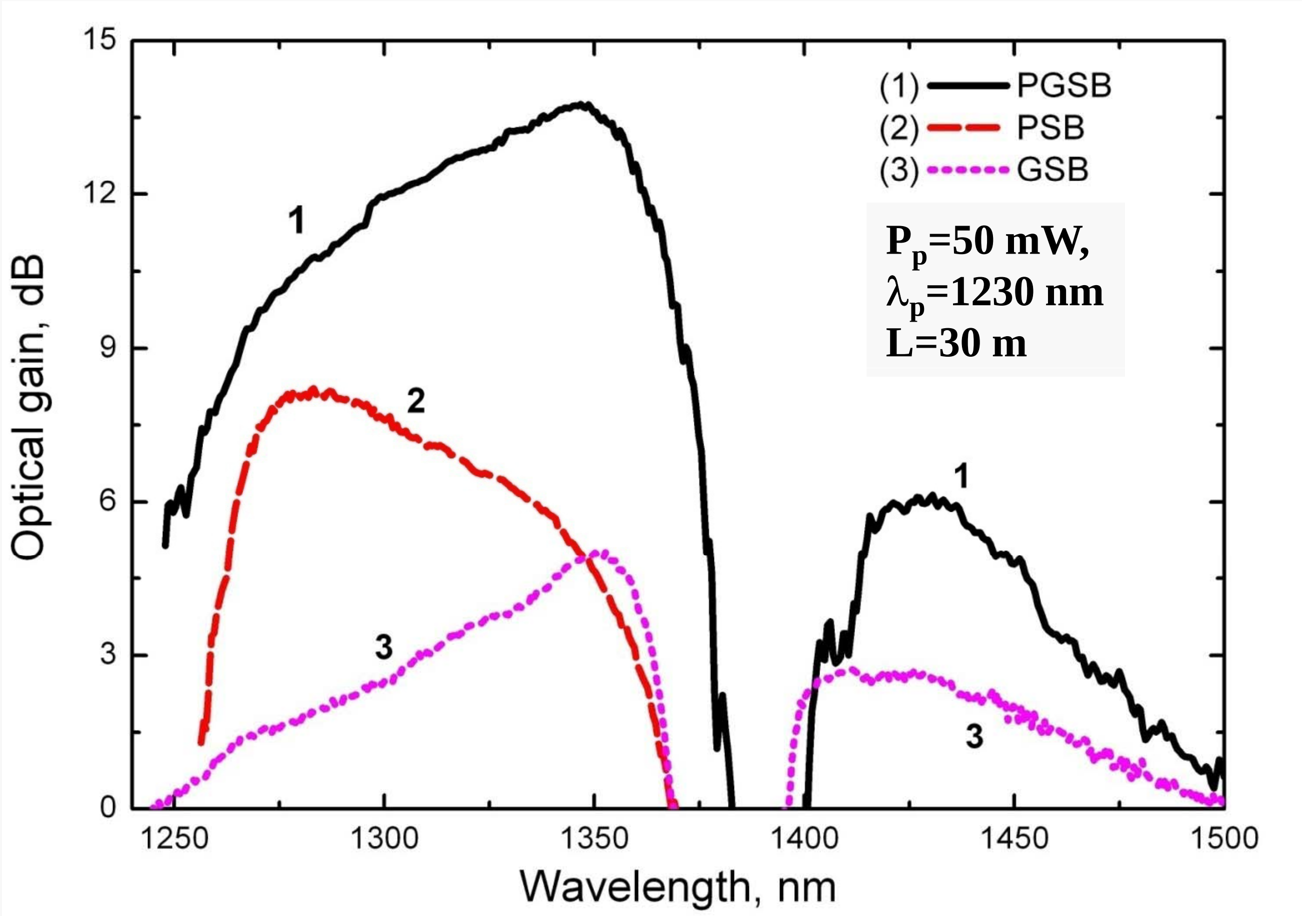
On/off gain spectra of PGSB, PSB and GSB fibers



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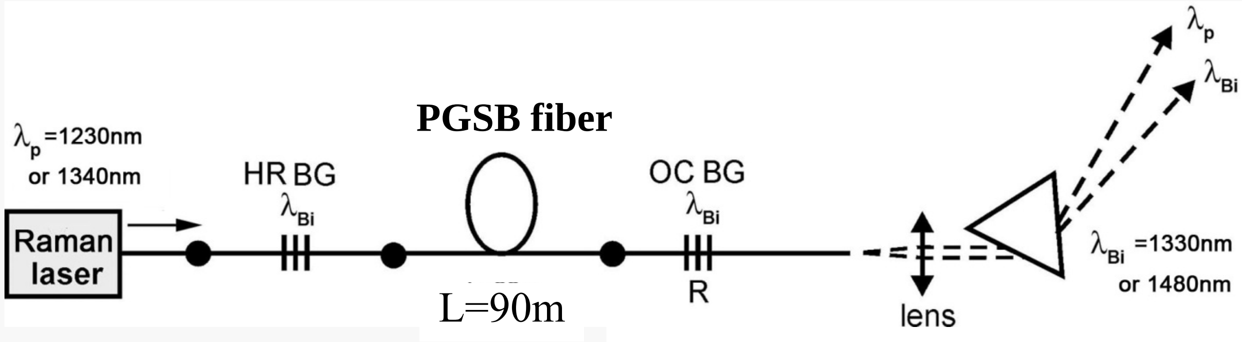
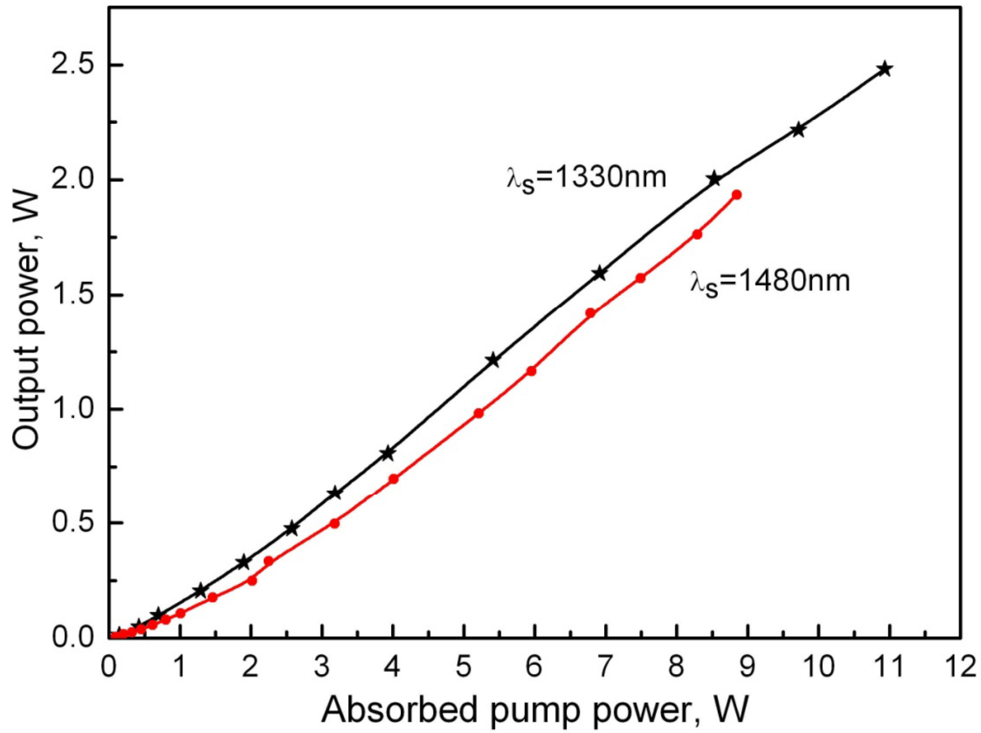
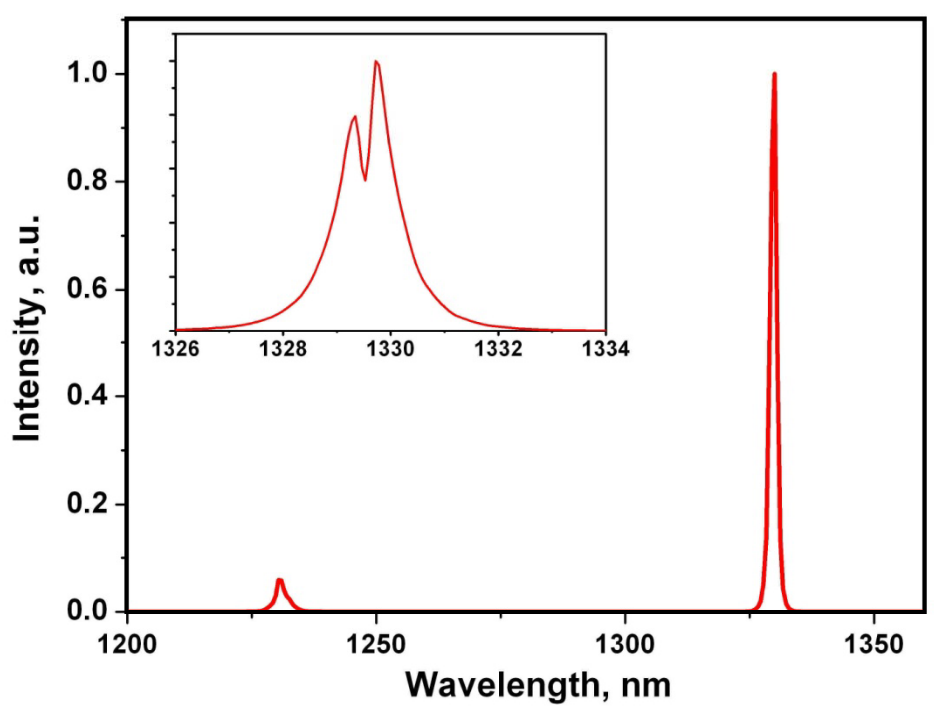
Watt-level Bi-doped fiber lasers, operating at 1300 – 1500 nm

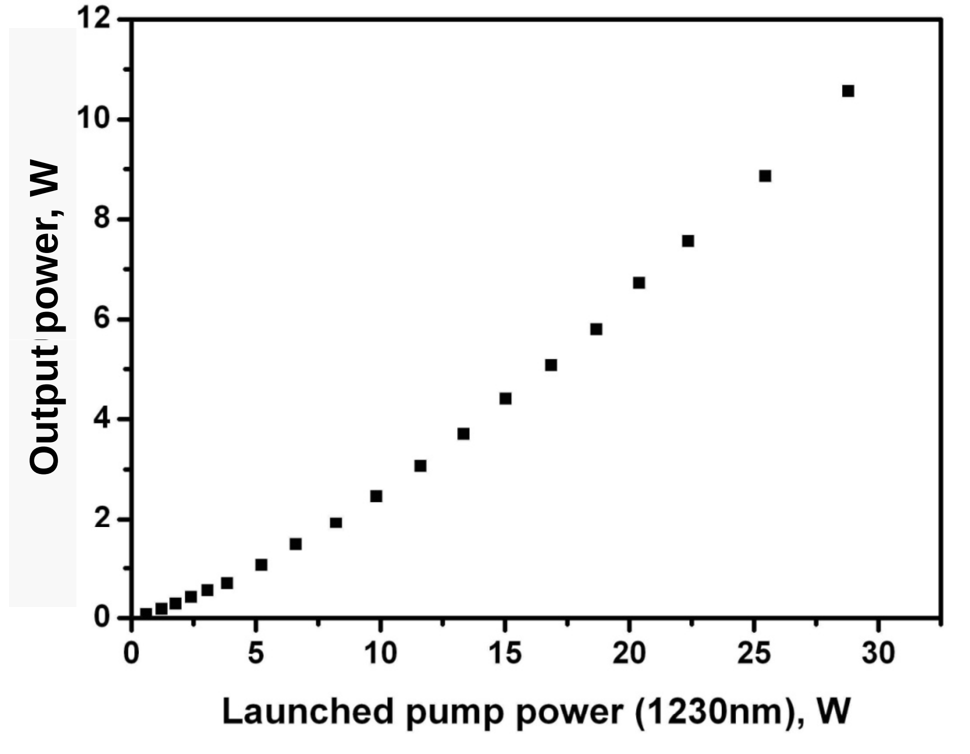




I.A.Bufetov et al., submitted to ECOC'2009.

10W Bi-doped fiber laser at 1330 nm





A.V.Shubin et al. Quantum electronics, 2009 (to be published).

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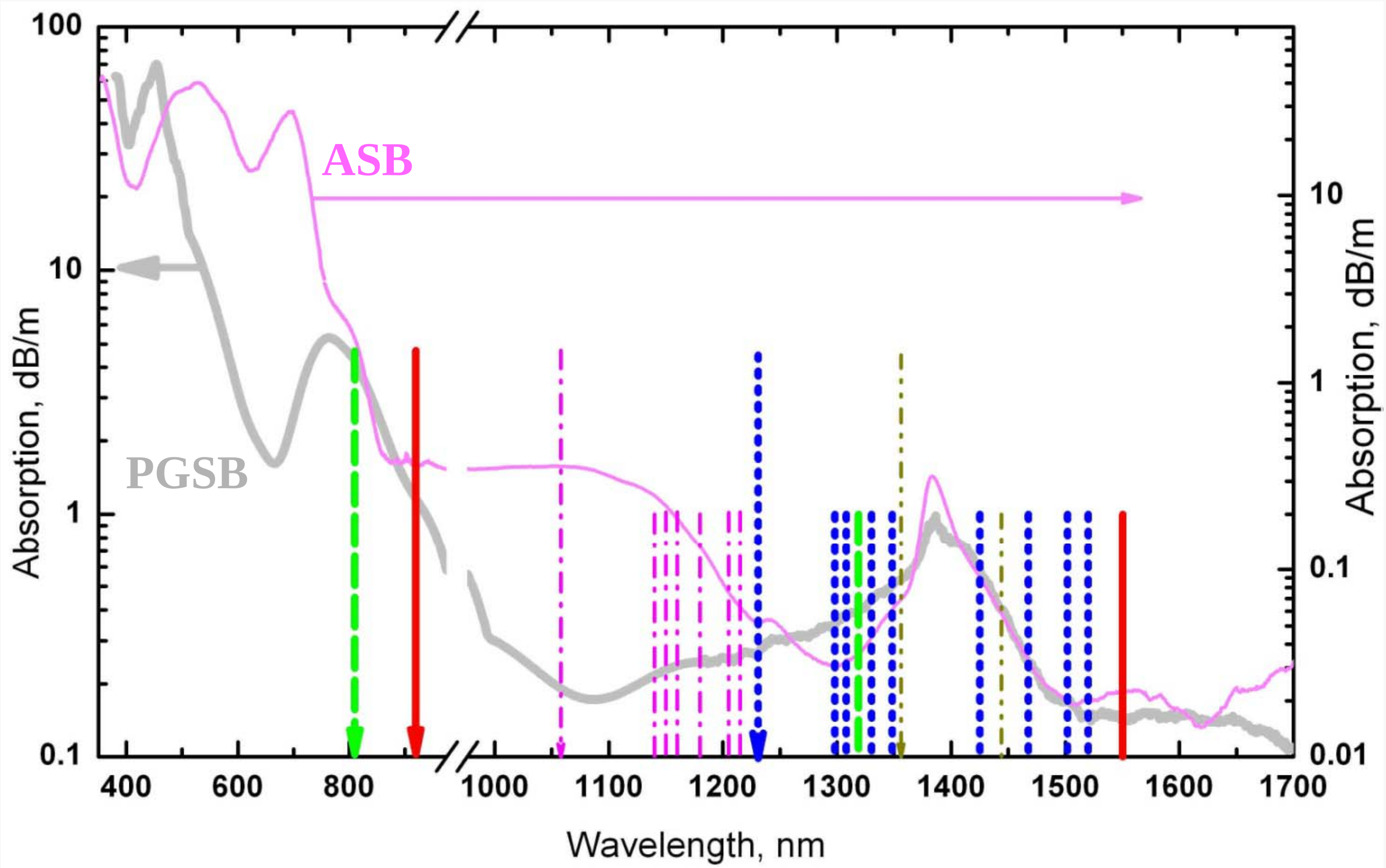
Laser generation wavelengths obtained in ASB and PGSB fibers at various pump wavelengths



Arrows indicate pump wavelengths; laser and corresponding pump wavelengths are shown by lines of the same type.

Possible applications of Bi-doped fiber lasers and amplifiers

- optical fiber communication systems using a spectral region of 1300-1500 nm for transmission
- frequency-doubled Bi-doped fiber laser operating at 570-750 nm
  - ophthalmology and dermatology
  - laser guide star for adaptive optics of large optical telescopes (589 nm)
- generation of ps and fs pulses in a spectral region of 1140-1500 nm

Conclusion

- Efficient generation of Bi-doped fiber lasers in a spectral region of 1140-1550 nm is a new breakthrough in laser technique
- Further fundamental researches are necessary to clear up the nature of Bi-connected active centers, which is unsolved problem yet