A Novel Multipass Optical System

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BACKGROUND

Multipass optical systems (MOS) are broadly used in absorption, Raman, fluorescence, and ionization laser spectroscopy; and also in Raman lasers, laser amplifiers and optical parametric oscillators [1]. Traditional MOS are not universally applicable and have many disadvantages. They can not provide homogeneous illumination of optically transparent medium with different heights, widths, and lengths; all beams can not be focused into one point; sometimes the number of passes which can be obtained with them are insufficiently small. Depending on the optical task, not very rare, rather complicated types of MOS have to be designed with specialized for every project optical elements, primarily convex mirrors.

DESCRIPTION OF THE MOS

To the best of our knowledge, this work presents a novel, simple and more universal MOS design allowing to create either all beams focused or after minor modification homogeneous, equidistant illumination of areas with practically any heights (H+h), widths (W) and lengths (L) (see Fig.1 and Fig. 2). The MOS use right angle prisms, however, retro-reflecting (folding) mirror also can be used instead of prisms [2]. In Figures 1, 2, and 3 matrixes are presented showing where and in what order laser beams cross hypotenuse surfaces (H-surface). A surface belonging to the cathetus (leg) of the prisms will be called C-surface. The green lines at matrixes show where and how right angle edges of prisms are positioned. In Fig. 3 one of the modification of the MOS is shown having four (A, B, C, and D) right angle prisms and two convex lenses. For simplicity, only first 11 passes are pictured in Fig.3 and only first 40 crosses of H-surfaces are shown in the matrixes. This MOS can be considered universal because using only four prisms homogeneous illumination of the area can be created with 20 laser beams and 40 passes. This can be done if lenses are removed, the prisms C and D are shifted vertically up, and prism B instead being under prism A put at the top of it.

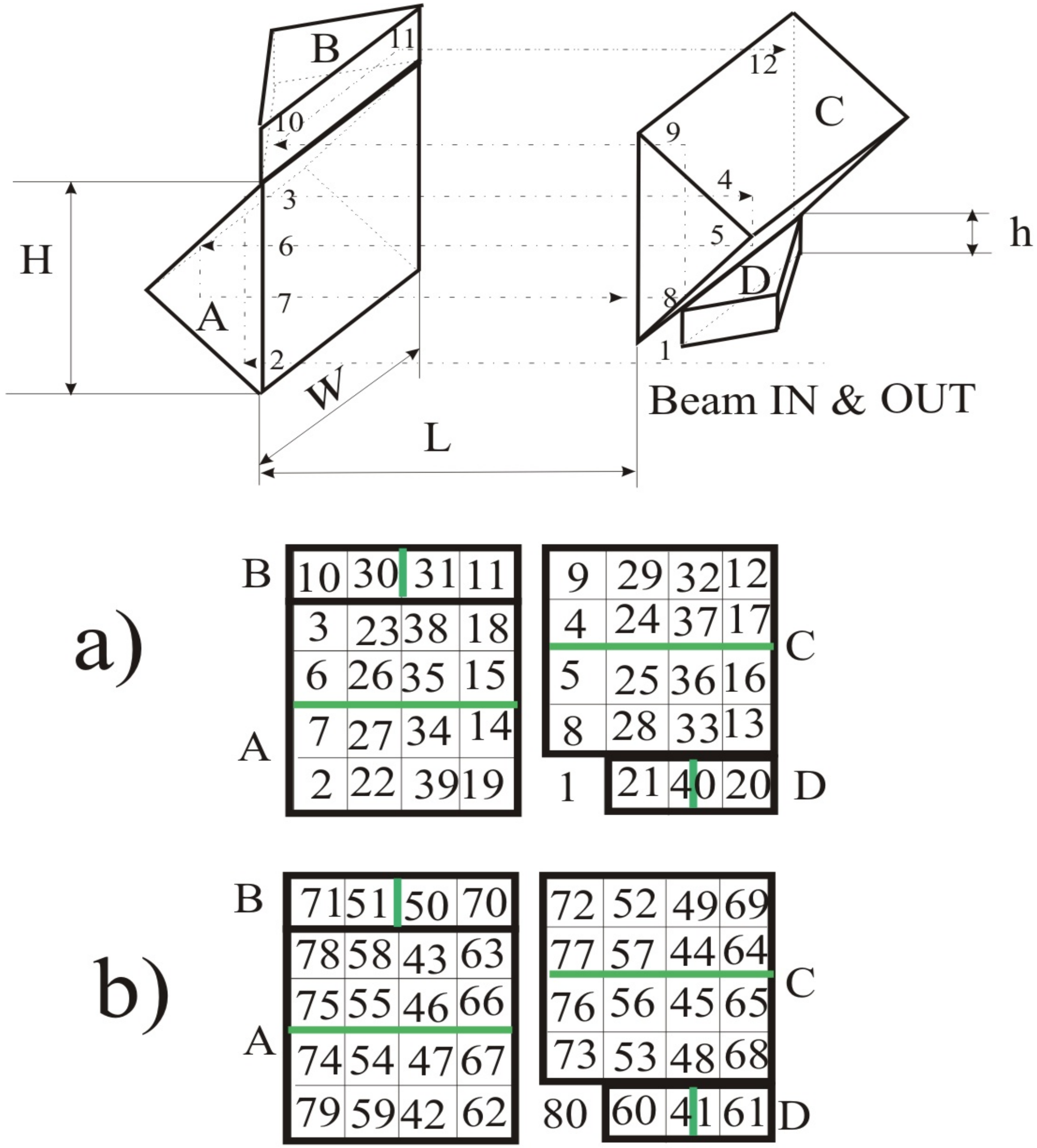


Fig 1. Three dimensional MOS with 40 passes.

a) matrix for the first 40 crossings of prisms surfaces;

b) matrix for the last 40 crossings of prisms surfaces;

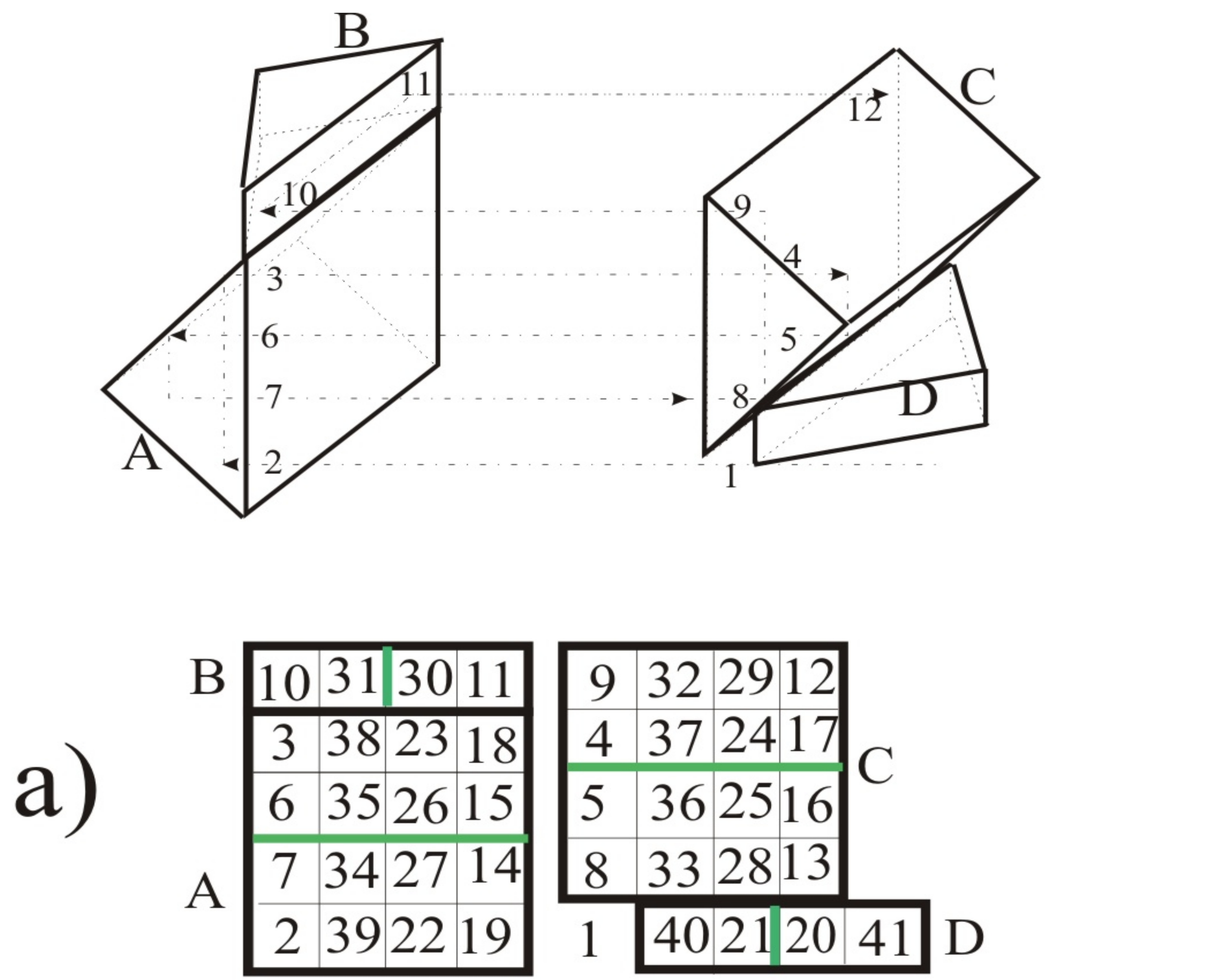


Fig 2. Three dimensional MOS with 21 passes.

a) matrix with 41 crossings of prisms surfaces;

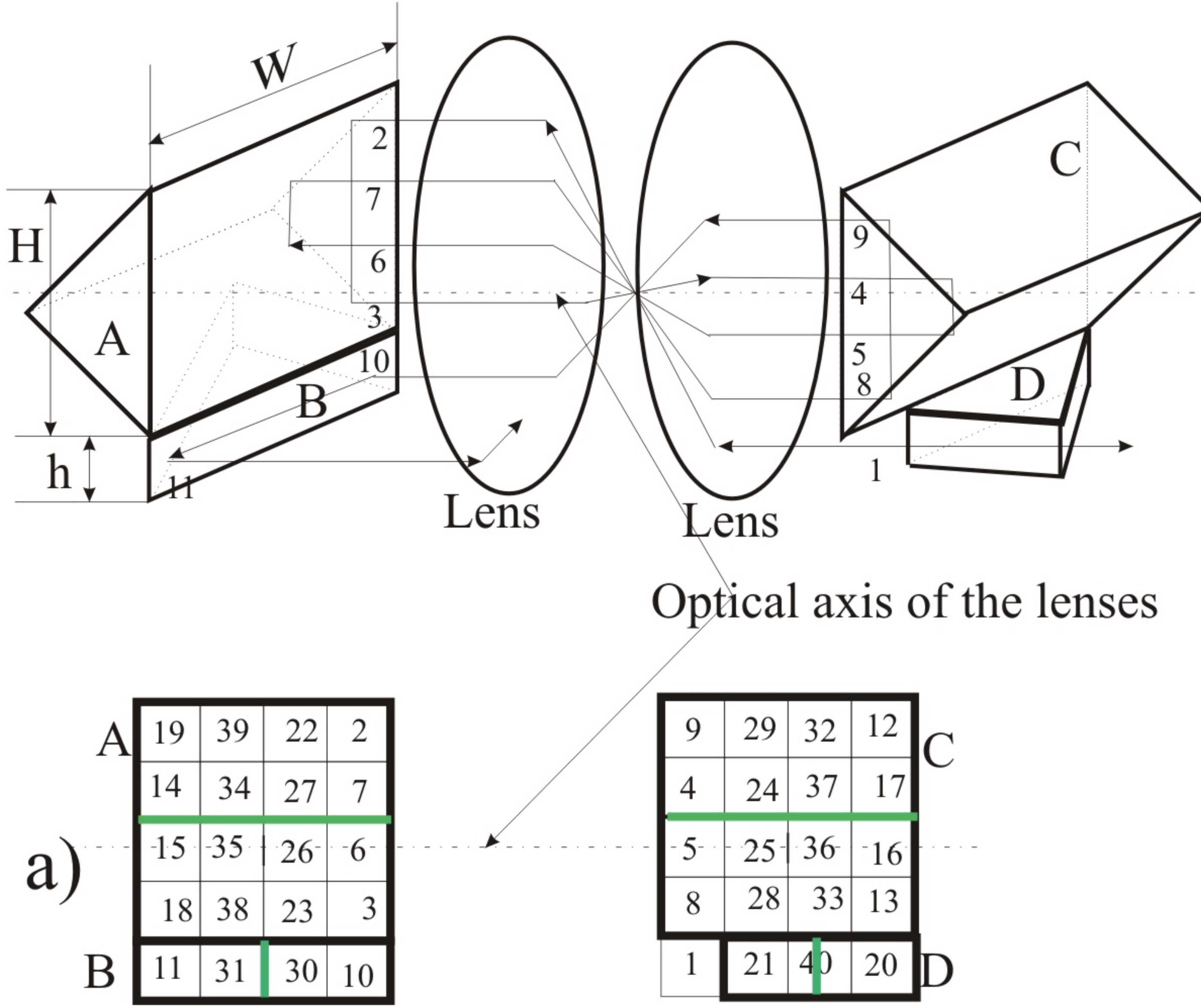


Fig. 3. Three dimensional MOS with focusing lenses.
a) matrix with the first 40 crossings of prisms surfaces;

COMPUTER SIMULATIONS

The simulations of laser beams propagations for various modifications of MOS had been done using optical design software OptiLab 522 made by a *Science Lab Software* company, CA, USA. All simulations had been done with nondivergent beams. In every picture the spots diagrams are also shown. The results presented in Figures 4,5 demonstrate that every big prisms in Fig.1-3 can be assembled from smaller prisms providing more flexibility in the number of passes and beams directions. For the MOS geometry depicted in Fig.4 when size of laser beam is increased to 8 mm almost homogeneous filling by laser light occur with 182 total number of passes.

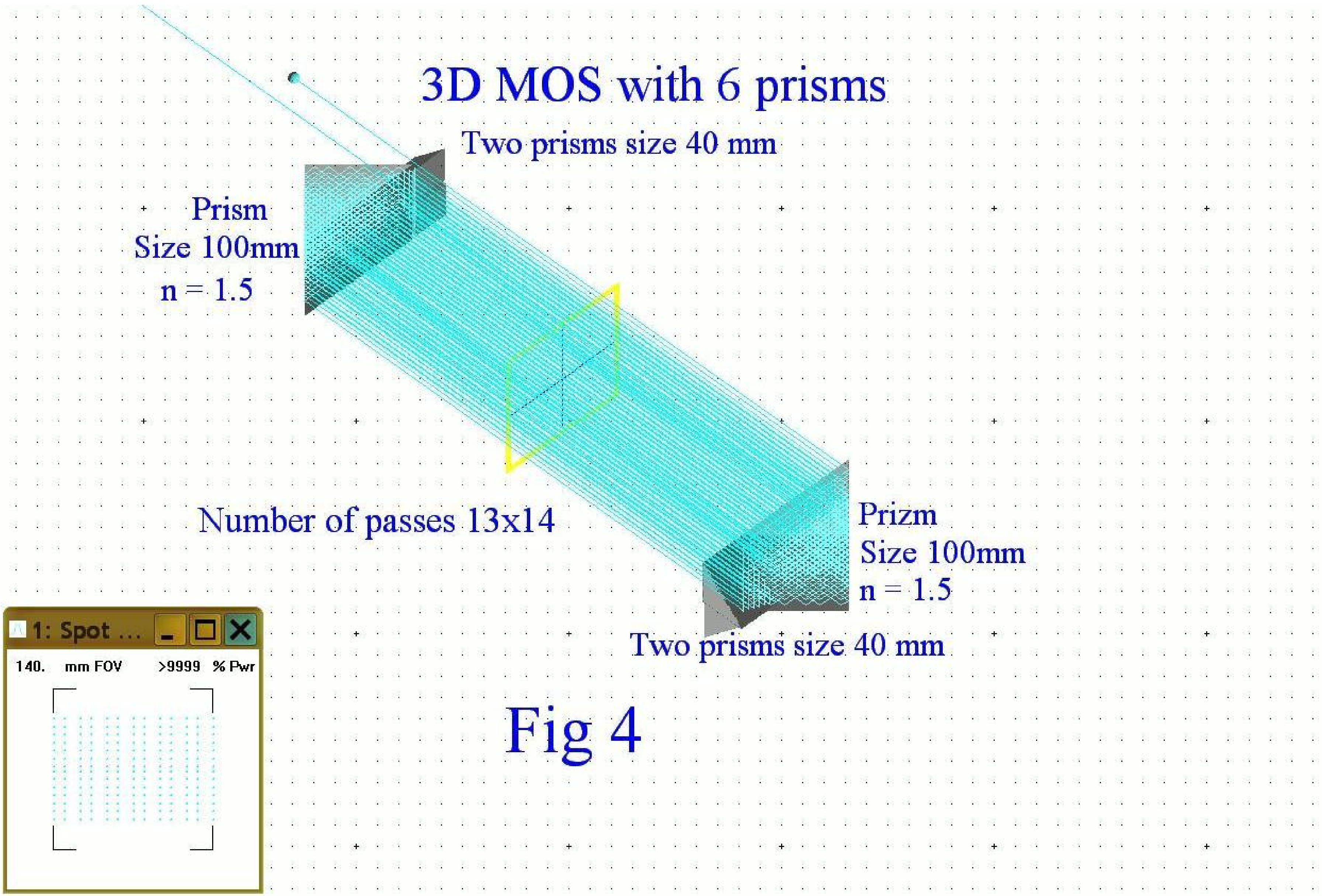

3D MOS with 6 prisms
Two prisms size 40 mm
Prism
Size 100mm
n = 1.5
Number of passes 13x14
Prizm
Size 100mm
n = 1.5
Two prisms size 40 mm
1: Spot ...
140. mm FOV >9999 % Pwr

Fig 4

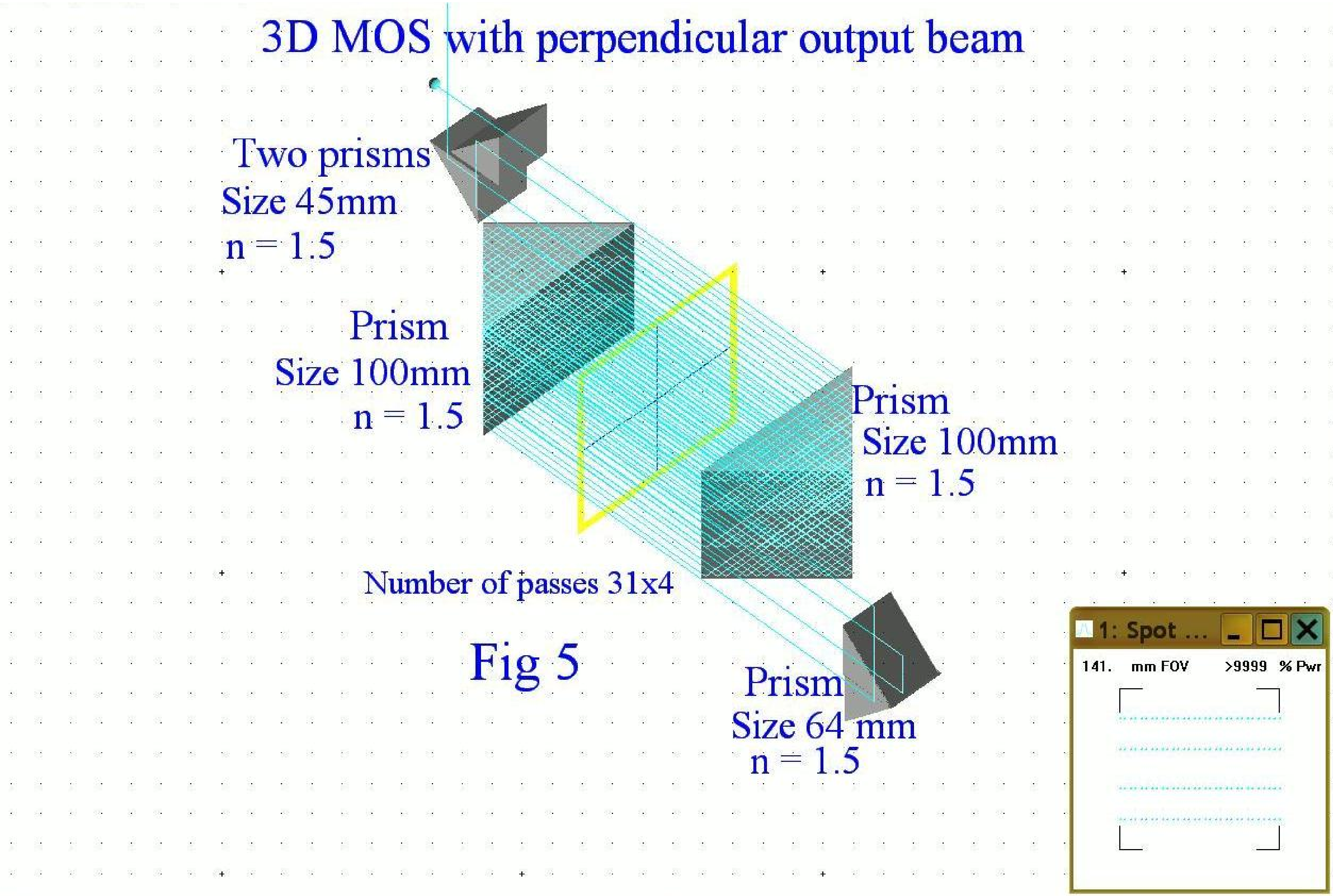

3D MOS with perpendicular output beam
Two prisms
Size 45mm
n = 1.5
Prism
Size 100mm
n = 1.5
Prism
Size 100mm
n = 1.5
Number of passes 31x4
Prism
Size 64 mm
n = 1.5
1: Spot ...
141. mm FOV
>9999 % Pwr

Fig 5

As it is known antireflection coatings (AR) are working only in rather narrow spectral range. For polarized beams the MOS shown in Fig. 6 can work without AR in a very broad spectral range because it uses prisms design with Brewster angle incidence. For example, if the prisms made of quartz they can used for wavelengths from 0.2 to 2.2 micrometer. Another interesting situation was observed (see Fig.7) when one of the convex lenses was replaced by a concave one, creating a sort of telescope. In this case the 1.5 mm diameter beams become “compressed” providing almost homogeneous 25 passes illumination in a small 3.5 x 0.3 mm area.

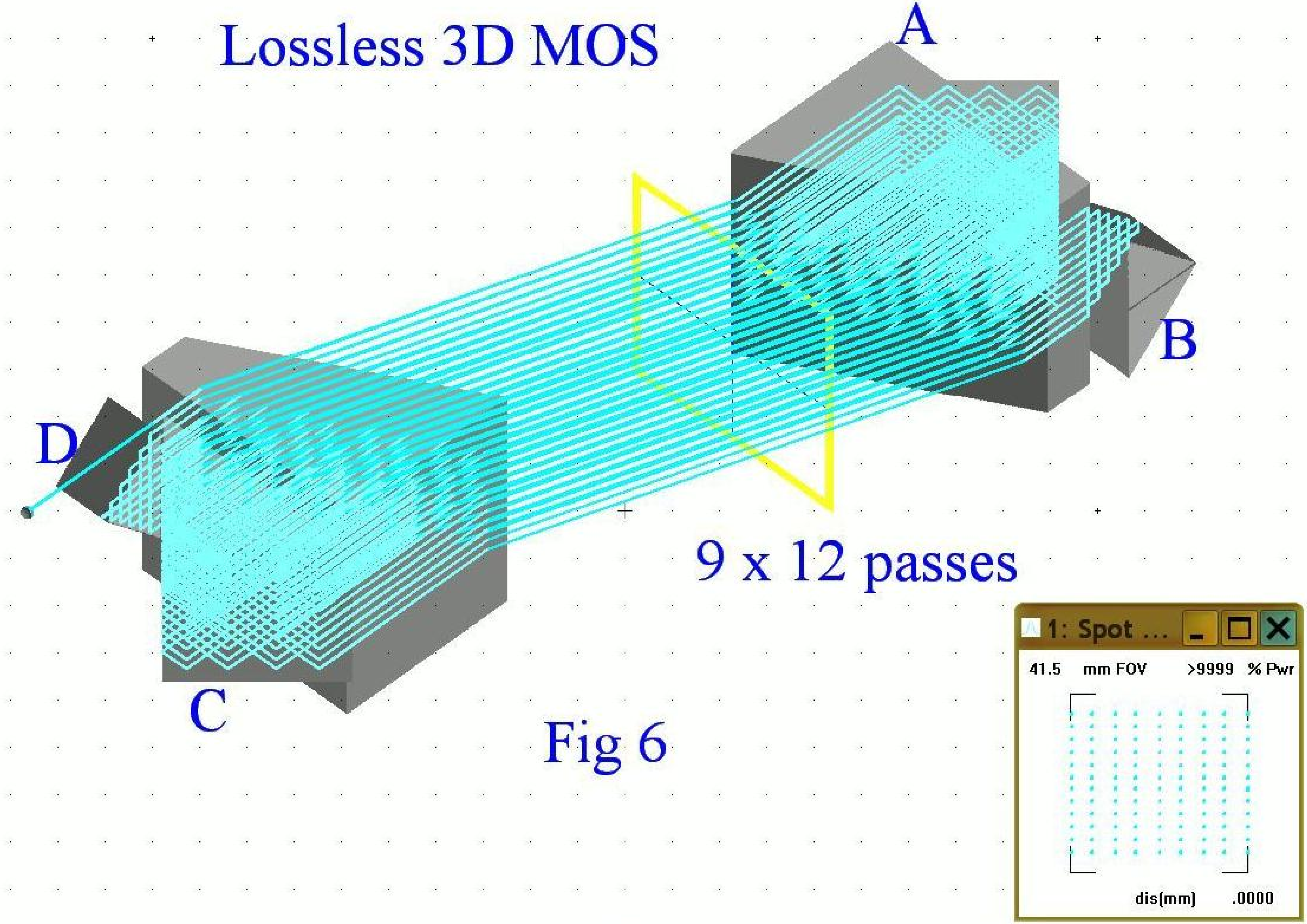

Lossless 3D MOS
A
B
C
D
9 x 12 passes
1: Spot ...
41.5 mm FOV
>9999 % Pwr
dis(mm) .0000

Fig 6

MOS with a telescope

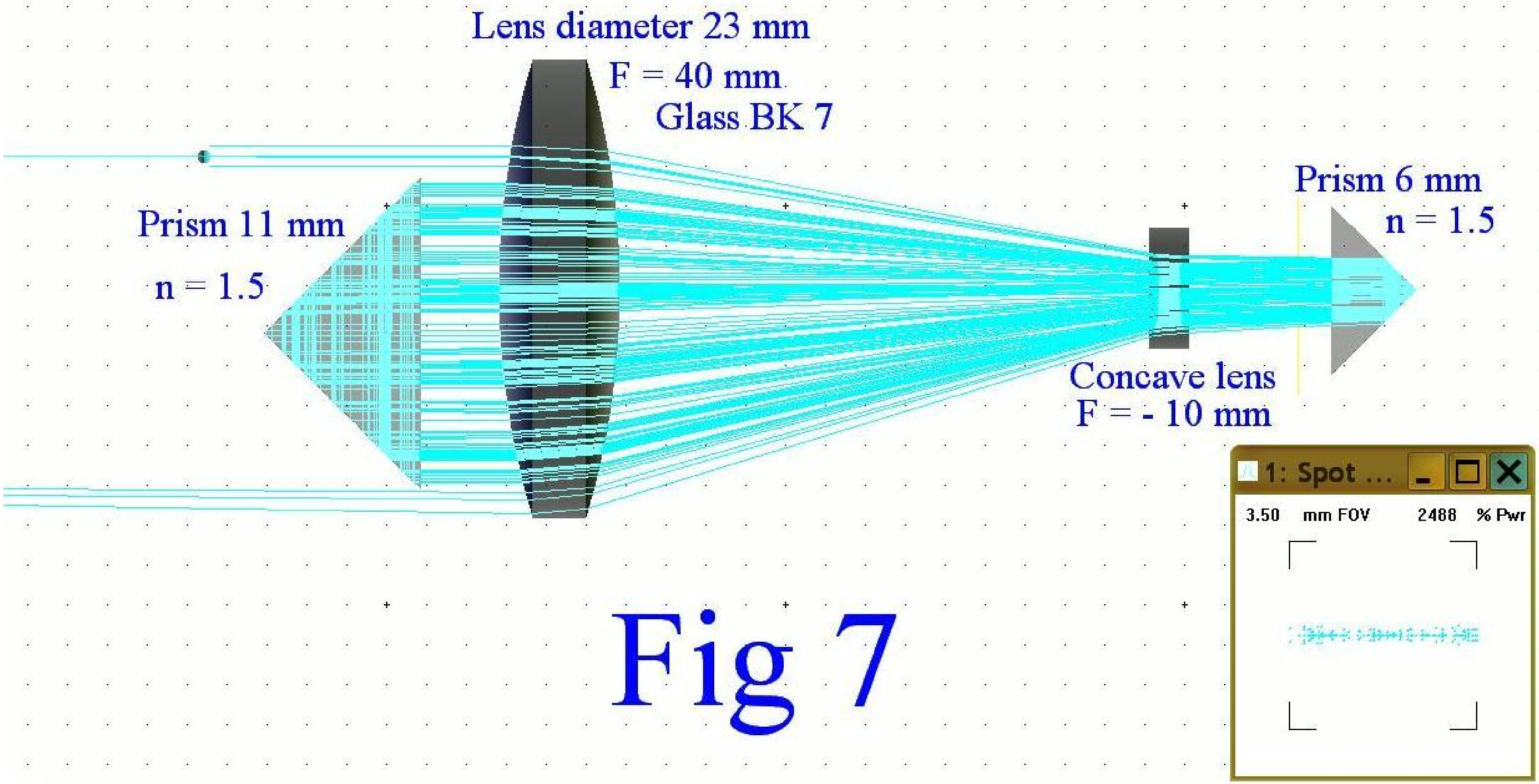
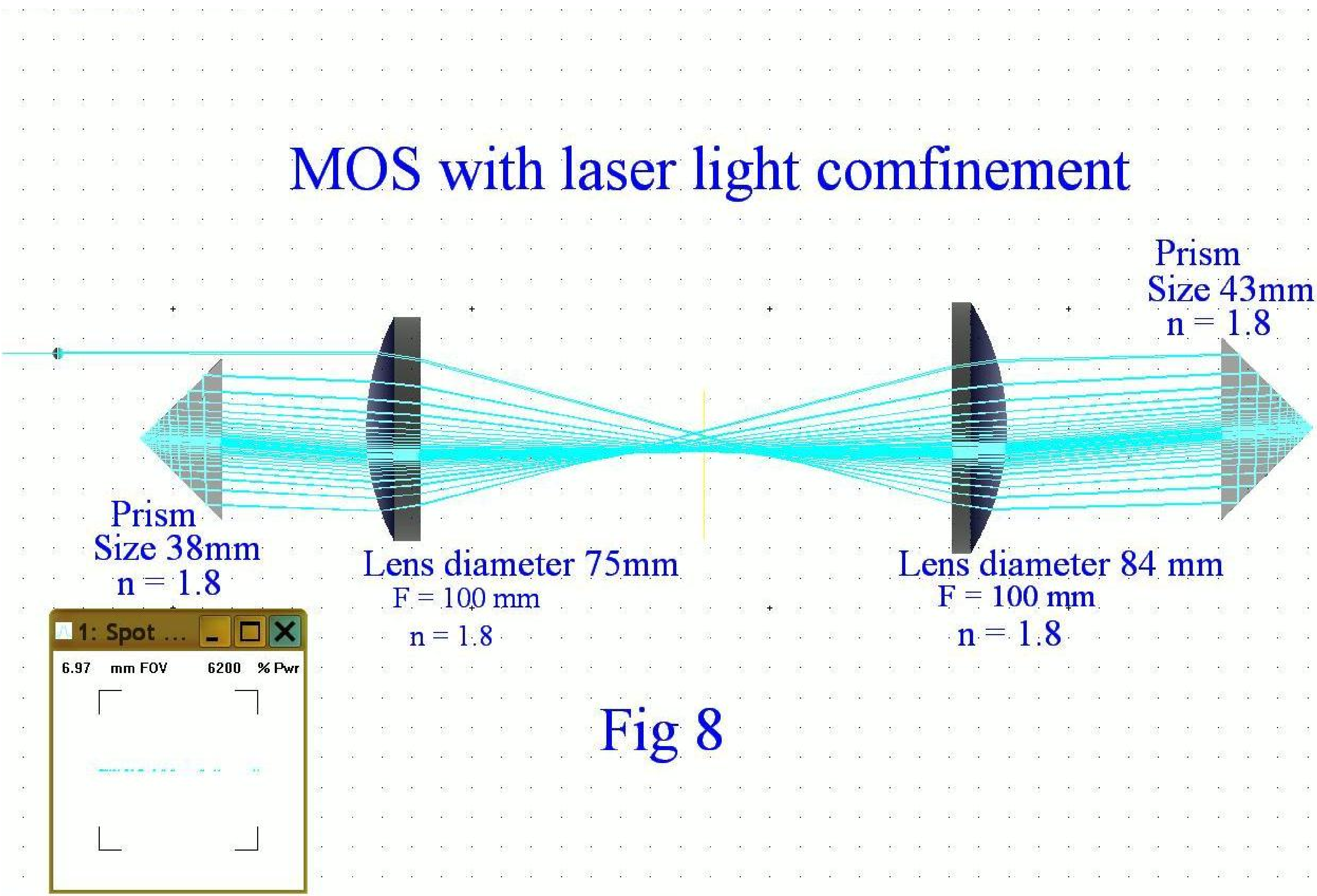


Fig 7

As it was found, remarkable feature of the novel MOS is its ability, in some cases, to provide confined (Fig.8) beams in the illuminated areas with a number of passes limited only by the reflection losses on the optical surfaces. Geometrically, when there are no lenses the MOS in Fig.8 allows only 16 passes, however in the confinement geometry the number of passes, as seen, can be much higher. Instead of lenses spherical mirrors (Fig. 9) can be used in the cases when probe laser beam should be directed in parallel with main beam.


MOS with laser light comfinement
Prism
Size 43mm
n = 1.8
Prism
Size 38mm
n = 1.8
Lens diameter 75mm
F = 100 mm
n = 1.8
Lens diameter 84 mm
F = 100 mm
n = 1.8
1: Spot ...
6.97 mm FOV
6200 % Pwr
Fig 8

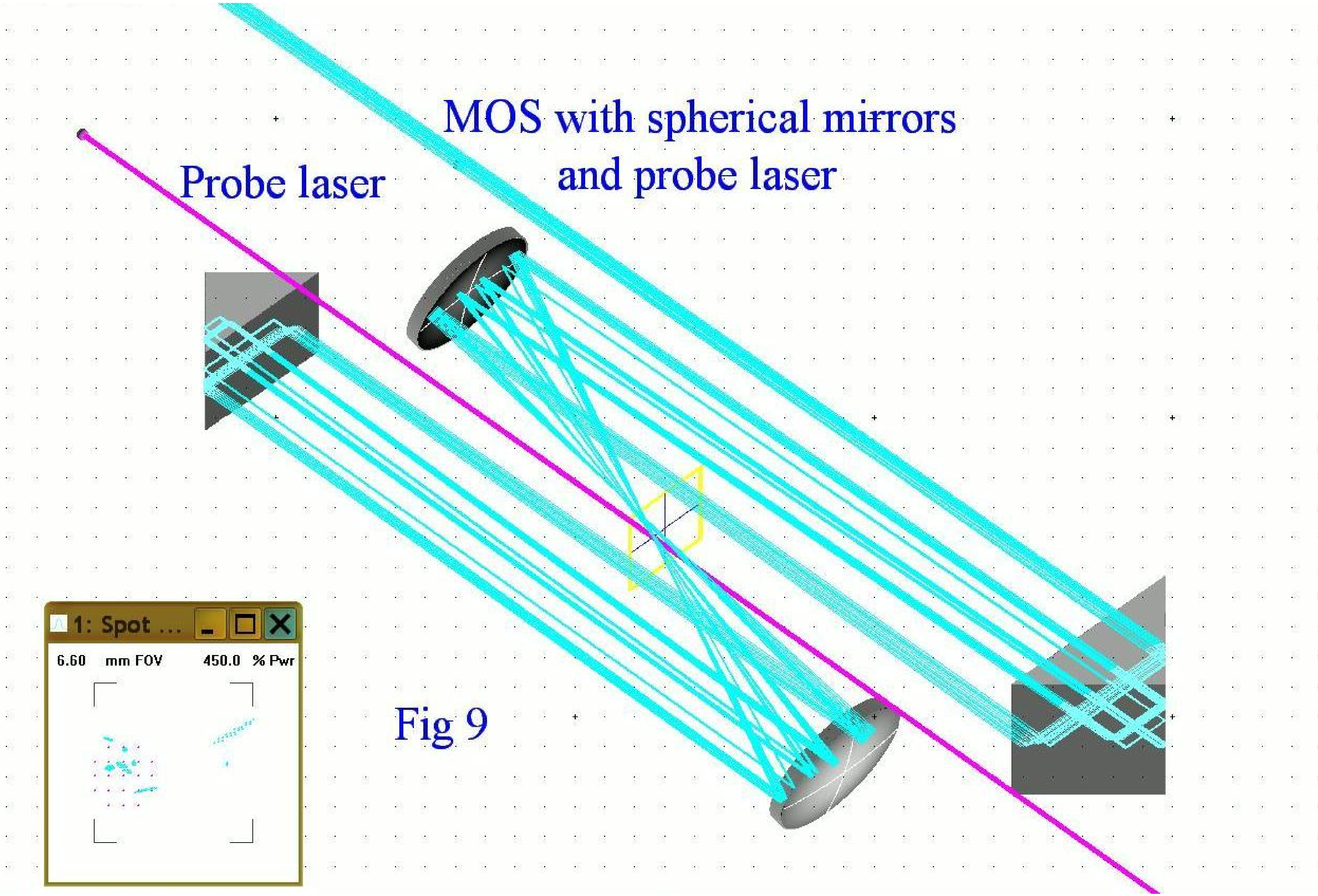

MOS with spherical mirrors
and probe laser
Probe laser
1: Spot ...
6.60 mm FOV
450.0 % Pwr

Fig 9

In comparison with traditional MOS having two mirrors and two reflecting surfaces, where loss of laser power can occur, our MOS can have six losses contributing surfaces. To avoid these losses MOS with combined, opticaly cemented prisms and lenses (Fig.10) can be designed, providing only two reflecting surfaces. Due to aberrations spherical lenses in some cases can not provide good focusing. Conversely, aspherical lenses as shown in Fig.10 can focus laser light much better. In all cases shown in figures 7-10 only two dimensional in one vertical plane beam propagations was simulated. However, all two-prism-lenses or -mirrors configurations shown in these figures can be designed with three dimensional four-prisms geometry presented in figures 1-3.

MOSes with combined prisms and lenses

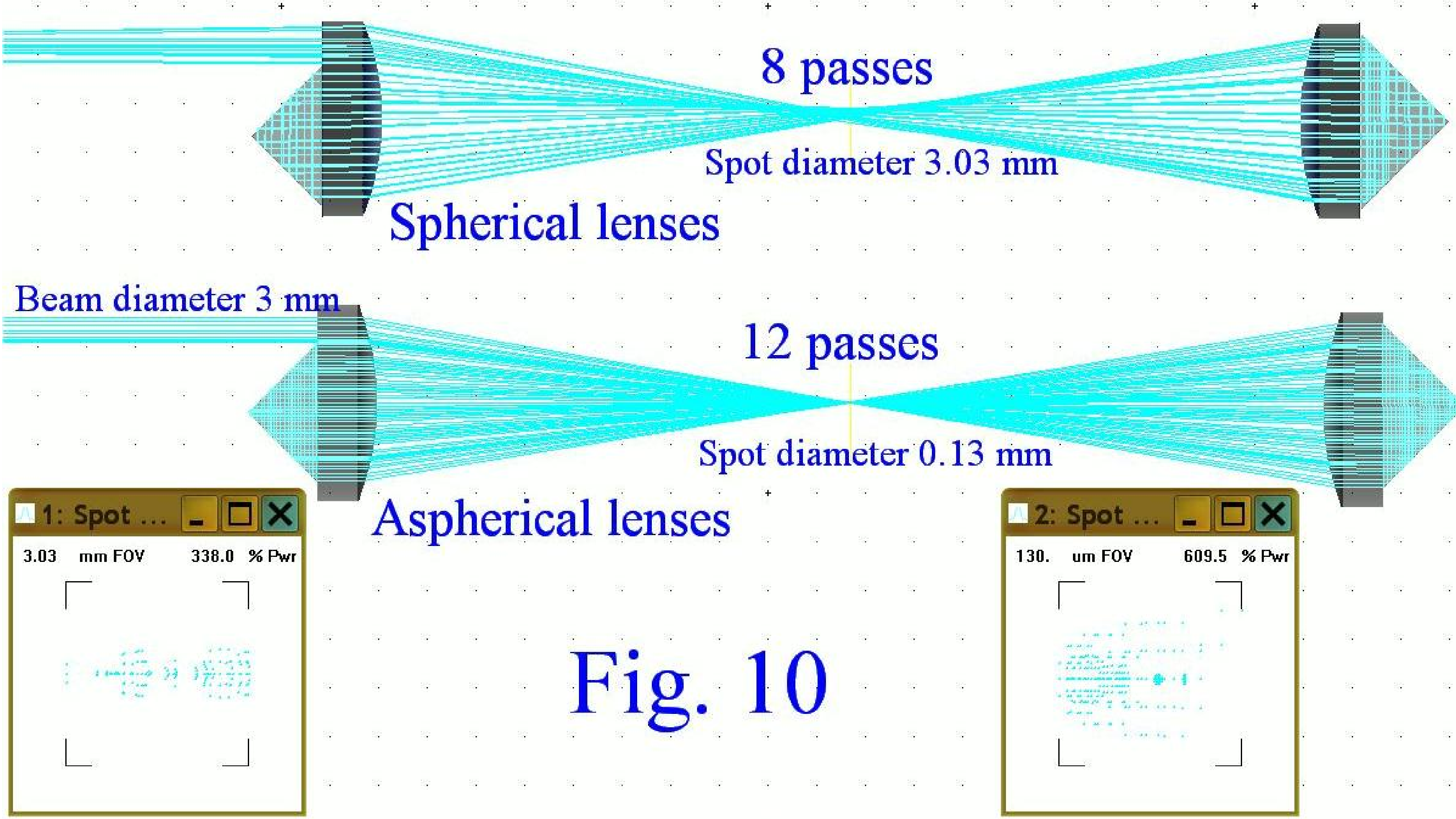


Fig. 10

ADVANTAGES

In laser spectroscopy and many other applications where laser radiation is used to illuminate transparent medium the universal MOS can provide many advantages in comparison with traditional MOS.

1. Number of passes can be as large as $2(H+h)W/h^2$ when beams are not focused.
2. Limited only by intracavity losses number of passes for focused beams.
3. Simple, inexpensive, high optical damage threshold design.
4. Can be designed for very broad spectral range (Fig. 6) without necessity for antireflecting or reflecting coatings.
5. The whole illuminated area can be filled by laser radiation evenly and homogeneously with any desirable width, length and height.
6. The MOS is universal: can work with lenses and without them; can provide variable distance between reflecting optical elements.

POTENTIAL APPLICATIONS

Because of many advantages the field of potential application for the MOS can be dramatically broader. The suggested multipass optical system can be used as an optical delay lines, light pulse stretching system; in Raman, CARS, absorption, laser enhanced ionization, resonance and multiphoton ionization, fluorescence, ionization, thermal lens, magnetic rotation of polarization plane spectroscopy and analysis; also for laser chemical reactors; for laser isotope separation; laser generators and amplifiers, for fast and slow rotating Q-switches of lasers; for Raman lasers and Raman frequency shifters; for second harmonics generators, optical parametric generators and amplifiers; atoms and molecules cooling; laser induced breakdown of air, liquids and gases; for different type of mutiphoton spectroscopy and analysis; precise distance measurements; for resonance ionization image detectors and resonance fluorescence imaging monochromators; for pico- and femtosecond spectroscopy and lasers; as a part of photoionization source in gas chromatography, mass spectrometry, ion mobility spectrometers, capillary and other type of electrophoresis, high performance liquid chromatography. Also it can be used for photofragmentation and after that fluorescence (or/and Raman, emission and chemiluminescence etc) analysis of many substances. One of the most important group of substances to be analyzed might be explosives. In this case the energy of laser for photofragmentation might be 10 -1000 times less than for single beam laser spectrometers, i.e. the whole system can be designed very portable. Focusing and MOS with light confinement can be used in compact generators of X-rays by inverse Compton scattering. Similar system, but with mirrors, is described in a paper [3]. Another important application can be direct and/or holographic information (including diffraction gratings, lenses etc) recording and reading in transparent medium.

One of the project currently under development is shown in Fig.11, where MOS with a telescope is used to illuminate and to ionize molecules in the FT-ICR mass-spectrometer cell. Another promising application for Raman spectrometer is shown in Fig.12.

Preliminary experiments had been done using planar MOS with two simple spherical focusing lenses. A cuvette with various liquid organic solutions was illuminated by CW 50 mW 532 nm laser. The Raman signal was detected using CD 2000 digital spectrometer made by Ocean Optics Inc., Dunedin, FL, USA.   With two 10 and 12 mm right angle prisms the MOS provided 8 passes. Since lenses had not been corrected for aberrations and all surfaces was without antireflection coatings only five times improvement of Raman signal was achieved.

MOS for FT-ICR mass spectrometer

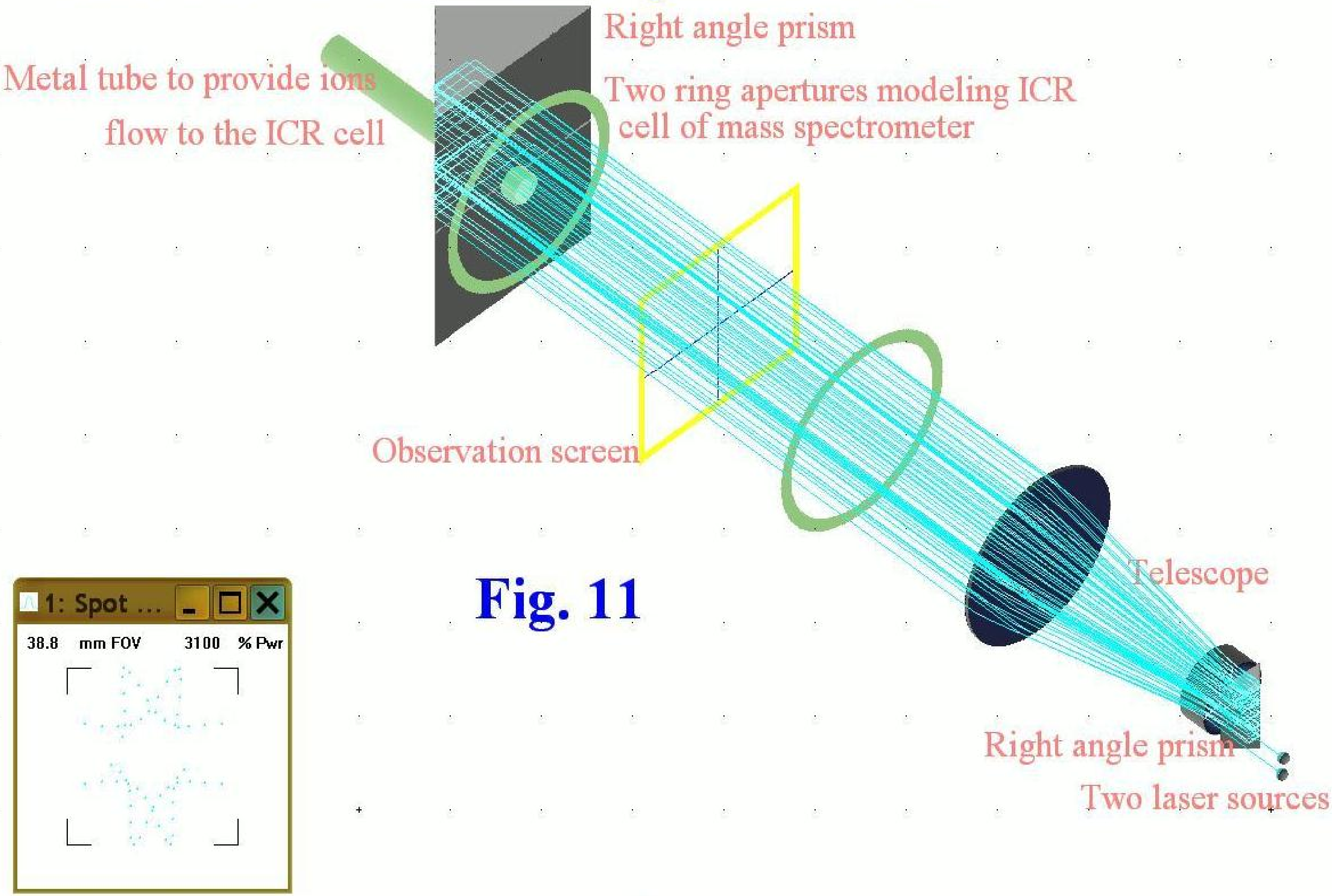


Fig. 11

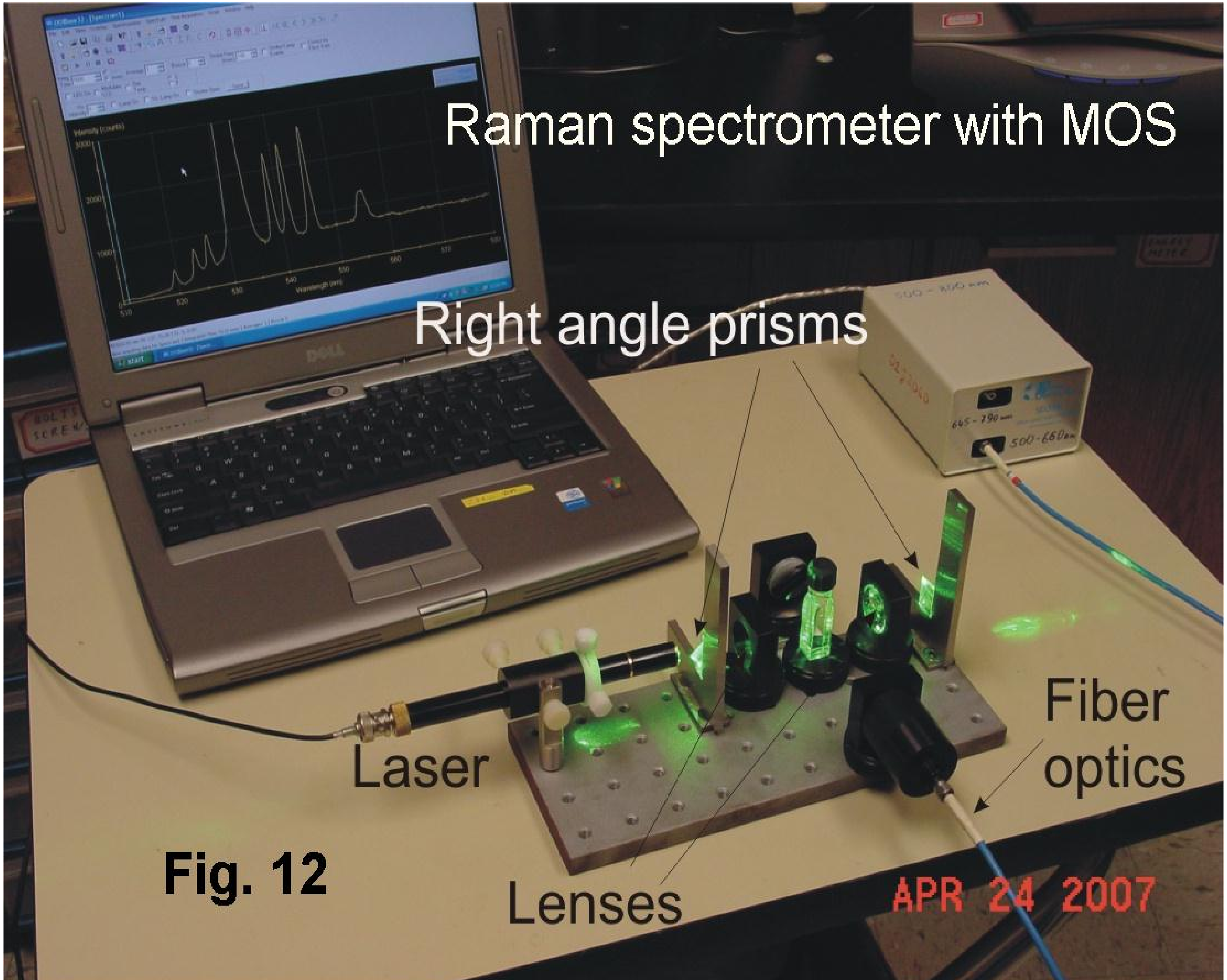

Raman spectrometer with MOS
Right angle prisms
Laser
Lenses
Fiber optics
APR 24 2007

Fig. 12

FUTURE RESEARCH

To reveal the applicability potential and usefulness of the described MOS further experimental and theoretical research has to be done on many topics:

1. Performance of the MOS with divergent laser beams; Gaussian and homogeneous beams.
2. Effects of wave nature of the lights on MOS performance: interference and diffractions.
3. Nonflat (spherical, aspherical) C- and H-surfaces; aspherical lenses.
4. Effects and influence of different types of antireflection coatings on H-surfaces.
5. Optimal parameters of laser radiation and optics geometry have to be found to achieve maximum number of passes for the MOS with confined laser beams .
6. Elaboration of recommendation on selection of correct design and optimization of MOS parameters while solving real tasks in different areas of application.
7. Optimal focusing MOS design and geometry to get maximum irradiance in the focal point for CW and different types of pulsed lasers.

REFERENCES

1. S. M. Chernin, J. Mod. Opt., 48, **(2001)** 619-632.
2. M. J. Scaggs, US patent # 6081542, **(2000).**
3. A.J. Rollason, et al , Nuclear instruments and Methods in Physical Research , A 526, **(2004)** 560-571.