

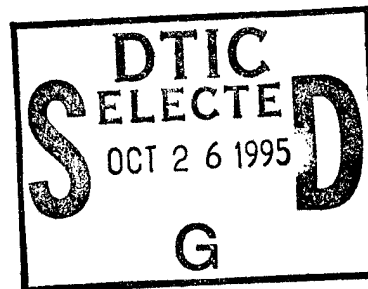
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1                                    A DUAL WAVELENGTH SURGICAL LASER SYSTEM

2  
3    1.    Field of the Invention

4            The present invention relates to lasers and particularly to  
5    a dual wavelength surgical laser system that would inflict  
6    significantly less collateral tissue damage during surgery than  
7    currently available scalpels or medical lasers.

8  
9    2.    Description of the Related Art

10           Lasers are currently employed in a wide variety of surgical  
11    applications. A major disadvantage encountered in laser surgery  
12    is collateral tissue damage. Such damage frequently results in  
13    longer healing times, accompanied by an increase in scarring. It  
14    has been fairly well established that collateral damage is caused  
15    by thermal diffusion and/or shock waves, and efforts have been  
16    made to reduce the damage by judicious selection of laser  
17    wavelength and pulse width. Until very recently, tissue ablation  
18    models employed in that selection process were based on a  
19    detailed understanding of the properties of water. Although  
20    water is the principal constituent of all biological tissue, it  
21    does not determine all the physical properties involved in the  
22    tissue ablation mechanism. Mechanical properties in particular  
23    are determined primarily by protein constituents such as  
24    collagen, lipoproteins and proteoglycans. With the availability

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1 of the medical free electron laser (FEL) at Vanderbilt University  
2 Medical Center (VUMC) it has now become possible to investigate  
3 the role played by the protein constituents in the laser tissue  
4 ablation process. This is accomplished by irradiating into known  
5 amide absorption bands in the spectral region between 5.9  $\mu\text{m}$  and  
6 6.6  $\mu\text{m}$ , which have varying degrees of overlap with the absorption  
7 due to the bending mode of water. In a most recent FEL study of  
8 corneal, dermal and neural tissue, which covered the spectral  
9 range between 2.5  $\mu\text{m}$  and 6.85  $\mu\text{m}$ , VUMC scientists observed  
10 maximum ablation rate and minimum collateral damage when they  
11 tuned to the amide-II band near 6.45  $\mu\text{m}$ .

12 These exciting new FEL results have raised several basic  
13 questions about the fundamental mechanism of laser ablation, and  
14 they suggest the possibility of designing a surgical laser which  
15 could inflict significantly less collateral tissue damage during  
16 surgery. VUMC scientists have proposed a dual-mechanism model to  
17 explain their FEL results. Qualitatively, their model assumes  
18 that laser energy absorbed into the protein and into the water  
19 perform two separate functions. The former serves to weaken the  
20 mechanical structure of the irradiated tissue volume, and the  
21 latter provides the "thermal explosion" to blow out the  
22 structurally weakened material. The highly favorable results  
23 obtained for FEL ablation of corneal tissue were tentatively  
24 attributed to the approximately equal partition of absorbed 6.45

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1  $\mu\text{m}$  radiation between the protein and the water. If this  
2 interpretation is correct, then it may also be possible to obtain  
3 even more favorable results by optimizing the partition of the  
4 absorbed energy. There has not yet been any clear indication that  
5 equipartition is optimal, nor that one specific partition of the  
6 energy will be favorable for all tissue types.

7 At the present time, applicants know of no prior art dual  
8 wavelength surgical laser used for precision surgery.

9  
10 Summary of the Invention

11 It is therefore an object of the invention to provide a  
12 surgical laser that would inflict significantly less collateral  
13 tissue damage during surgery than currently available scalpels or  
14 medical lasers.

15 Another object of the invention is to provide a dual  
16 wavelength surgical laser system for performing laser surgery on  
17 living tissue with a minimum amount of collateral tissue damage.

18 Another object of the invention is to provide a tunable dual  
19 wavelength surgical laser system for producing a sequence of  
20 protein and water absorption light pulse pairs, with each protein  
21 absorption light pulse softening the tissue and the following  
22 water absorption light pulse in a pulse pair acting to remove the  
23 softened tissue.

24 Another object of the invention is to provide a dual

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1 wavelength surgical laser system for producing a sequence of  
2 protein and water absorption light pulse pairs in which the ratio  
3 of light amplitudes in each pulse pair can be changed to  
4 compensate for a different type of living tissue having laser  
5 surgery performed thereon.

6 A further object of the invention is to provide a tunable,  
7 amplitude-variable, dual wavelength surgical laser system for  
8 performing laser surgery on different types of living tissue with  
9 a minimum of collateral tissue damage.

10 These and other objects of this invention are achieved by  
11 providing a dual wavelength surgical laser system comprising:  
12 a pump laser for emitting pump laser pulses of light at a  
13 preselected pump wavelength; an optical parametric oscillator  
14 responsive to each pump pulse from the pump laser for producing a  
15 first wavelength pulse of light in a water absorption band of the  
16 tissue and a second wavelength pulse of light in a protein  
17 absorption band of the tissue; a first set of optics for only  
18 passing therethrough each first wavelength pulse from the optical  
19 parametric oscillator; an optical delay line for delaying each  
20 first wavelength pulse from the first set of optics by a  
21 predetermined period of time; a second set of optics for only  
22 passing therethrough each second wavelength pulse from the  
23 optical parametric oscillator; and a beam combiner for combining  
24 each second wavelength pulse with the following delayed first

1 wavelength pulse to form a stream of consecutive second and  
2 delayed first pulse pairs for application to the tissue.

3

4 Brief Description of the Drawings

5 These and other objects, features and advantages of the  
6 invention, as well as the invention itself, will become better  
7 understood by reference to the following detailed description  
8 when considered in connection with the accompanying drawings  
9 wherein like reference numerals designate identical or  
10 corresponding parts throughout the several views and wherein:

11 Fig. 1 shows a schematic diagram of a preferred embodiment  
12 of the dual wavelength surgical laser system of the invention;

13 Fig. 2 shows the Type I Tuning Curve for the  $\text{AgGaSe}_2$  OPO  
14 utilized in the exemplary dual wavelength surgical laser system  
15 of Fig. 1;

16 Fig. 3 is a graph illustrating the protein and water  
17 absorption lines from the OPO of Fig. 1 for the tuning angle of  
18 47.3 degrees shown in Fig. 2; and

19 Fig. 4 is a graph showing the spectral output of the  
20 exemplary  $\text{AgGaSe}_2$  OPO of Fig. 1.

21

22 Detailed Description of the Preferred Embodiment

23 Before the invention is explained in detail, a brief  
24 overview of the operation of the invention will now be provided

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1 to aid in the understanding of the invention.

2 The phase matching angle of a tunable nonlinear crystal in  
3 the dual wavelength surgical laser system of the invention is  
4 adjusted to simultaneously produce a protein band light pulse and  
5 a water band light pulse at different wavelengths to enable  
6 independent irradiations into the water absorption band and the  
7 protein absorption band of tissue during laser surgery. The  
8 irradiation into the protein band softens the mechanical  
9 structure of the tissue, while the water irradiation produces  
10 what is called a "thermal explosion" of the tissue to push the  
11 tissue out. An adjustable delay line in the path of the water  
12 band light pulse is adjusted to vary the delay between the  
13 protein and water band light pulses in order to allow an optimal  
14 time for thermal relaxation of the mechanical structure once it  
15 has been excited by the protein band light pulse before the  
16 associated water band light pulse is applied. In order to  
17 account for the different requirements for different types of  
18 tissue on which to operate, the amplitude of the water band light  
19 pulse can be attenuated by an adjustable attenuator disposed in  
20 the water absorption line to obtain a different ratio of water  
21 absorption light to protein absorption light. A sequence of  
22 pairs of different light pulses, with each pair comprised of a  
23 protein band light pulse followed by a water band light pulse,  
24 are then fed into a fiber delivery system (not shown) for

1 surgical application.

2 Referring now to the drawings, Fig. 1 shows a schematic  
3 diagram of a preferred embodiment of the dual wavelength surgical  
4 laser system of the invention.

5 An exemplary Q-switched 2  $\mu\text{m}$  pump laser 11 is utilized to  
6 develop exemplary 2.05  $\mu\text{m}$  pump pulses. The Q-switched pump laser  
7 11 can be of the Q-switched Ho:YLF 2 $\mu\text{m}$  laser type described by C.  
8 L. Marquardt et al. in J. Appl. Phys., Vol. 54 (10), pp.5645-5646  
9 (Oct. 1983). However, it should be understood that any other  
10 suitable type of Q-switched laser pump source around 2  $\mu\text{m}$  can be  
11 used to produce the pump pulses. More particularly, the proper  
12 selection of a laser pump source would be required to optimize  
13 the surgery on any given tissue type to reduce collateral tissue  
14 damage by the judicious selection of laser wavelength and pulse  
15 width.

16 The 2  $\mu\text{m}$  pump pulses from the pump laser 11 are utilized to  
17 pump an optical parametric oscillator (OPO) 13. However, unless  
18 the OPO 13 is properly positioned in the beam path of the pump  
19 pulses and the pump pulses incident on the OPO 13 have the proper  
20 beam size and polarization, transfer optics 15 are required  
21 between the pump laser 11 and the OPO 13 to transfer the pump  
22 pulse light to the OPO 13 with the beam size and polarization  
23 needed for operation of the OPO 13. It should be noted at this  
24 time that both transfer optics and optical parametric oscillators

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1 are well known in the art.

2 The transfer optics 15 include whatever optics are required  
3 to transfer the pump pulse light from the pump laser 11 to the  
4 OPO 13 with the beam size and polarization needed for OPO  
5 operation. Anyone skilled in the laser art would be able to  
6 assemble the transfer optics 15 from standard optical components.  
7 One exemplary basic type of transfer optics 15 could include a  
8 passive turning mirror (not shown) for turning the beam at a  
9 right angle and a passive lens (not shown) for focusing the beam  
10 from the turning mirror into the OPO 13 with a desired beam size  
11 and polarization. The turning mirror could be any type of  
12 dielectric mirror which is coated for high reflectance (HR) at  
13  $2.05 \mu\text{m}$  (which is the wavelength of the pump pulses from the pump  
14 laser 11) and is positioned to have a 45 degree angle of  
15 incidence. The lens could be a single lens comprised of a fused  
16 silica substrate, be antireflective (AR) coated at  $2.05 \mu\text{m}$  and  
17 have a focal length (f.l.) of about 50 centimeters (cm).

18 The OPO 13 is placed at an appropriate position in the path  
19 of the focused beam from the training optics 15 to obtain the  
20 proper beam diameter. The OPO 13, in its simplest form, is  
21 comprised of mirrors 17 and 19 and a nonlinear optical crystal or  
22 nonlinear crystal 21. Examples of nonlinear crystals that may be  
23 used in the OPO 13 are silver-gallium-selenide ( $\text{AgGaSe}_2$ ) and  
24 zinc-germanium-phosphide ( $\text{ZnGeP}_2$ ). However, the preferred

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1 nonlinear crystal 21 is AgGaSe<sub>2</sub> because of its current  
2 availability and usual degree of optical perfection. The crystal  
3 21 is mounted on a rotation stage 23 to permit adjustment of the  
4 phasematching angle to tune the two wavelength outputs of the  
5 nonlinear crystal 21 (to be discussed). The rotation stage 23 is  
6 available from any vender of optical hardware listed in Laser  
7 Focus Buyers' Guide (LFBG). The AgGaSe<sub>2</sub> crystal is available from  
8 Cleveland Crystals, Inc. in Cleveland, Ohio. It should be  
9 realized that a rotation stage 23 may not be needed, if the exact  
10 output wavelengths (and particularly the exact protein absorption  
11 band - to be explained) is known and the OPO 13 is constructed  
12 with a high enough degree of precision to not require any  
13 adjustment.

14 The mirrors 17 and 19 in the OPO 13 can be obtained from any  
15 competent IR (infrared) coating house, but the mirrors 17 and 19  
16 actually used in the OPO 13 of Fig. 1 were specifically obtained  
17 from Laser Optics, Inc. with the following indicated  
18 specifications. Mirror 17 has a fused silica substrate, a 10  
19 meter radius of curvature (10 M RoC), a transmission better than  
20 93% at the pump wavelength of 2.05  $\mu\text{m}$ , and a reflectance greater  
21 than 99% at 3.01  $\mu\text{m}$ . Mirror 19, the output coupler, has a ZnSe  
22 substrate, is flat on both sides, and has a transmission better  
23 than 90% at 2.05  $\mu\text{m}$ , a reflectance of about 90% at 3.01, and a  
24 transmission of about 85% at 6.45  $\mu\text{m}$ .

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1           In operation, focused 2.05  $\mu\text{m}$  pump pulses from the pump  
2 laser 11 are directed by the transfer optics 15 into the OPO 13.  
3 These 2.05  $\mu\text{m}$  pump pulses are transmitted through mirror 17 into  
4 the nonlinear  $\text{AgGaSe}_2$  crystal 21. In response to the 2.05  $\mu\text{m}$   
5 pump pulses the  $\text{AgGaSe}_2$  crystal 21 generates two different  
6 wavelengths that are tunable between 2.65  $\mu\text{m}$  and 12  $\mu\text{m}$  by  
7 rotating the rotation stage 23 and, hence, the crystal 21 to a  
8 desired angle or phase matching angle (to be discussed more fully  
9 in relation to Fig. 2). In other words, for any given angle that  
10 is selected for a particular pump wavelength, the crystal 21 in  
11 the OPO 13 will develop two different wavelengths which will  
12 outputted from the OPO 13.

13           The rotation stage 23 can be rotated by means such as a  
14 motor (not shown) or a thumb screw (not shown) or any other  
15 suitable means for rotating the stage 23. As a result, the  
16 rotation of the crystal 21 can adjust the phase matching angle of  
17 the nonlinear  $\text{AgGaSe}_2$  crystal 21 to an exemplary angle of about  
18 47.3 degrees so that it simultaneously generates light at two  
19 different wavelengths (the idler and signal wavelengths) at 2.8  
20  $\mu\text{m}$  and 6.45  $\mu\text{m}$  respectively.

21           It should be noted at this time that the crystal 21 could  
22 also be tuned to produce a different pair of wavelengths that  
23 could be angle-tuned over a different range of wavelengths by  
24 utilizing a different type of pump laser 11 to produce a

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1 different pump wavelength.

2       The signal wavelength light can also be called protein band  
3 light, protein absorption band light or protein band absorption  
4 light because it is a band of wavelengths in the tissue that has  
5 a protein absorption. The idler wavelength light can also be  
6 called water band light, water absorption band light or water  
7 band absorption light because it is a band of wavelengths in  
8 which the tissue has a water absorption.

9       The protein band light at  $6.45 \mu\text{m}$  and the water band light  
10 at  $2.8 \mu\text{m}$ , as well as the pump light at  $2.05 \mu\text{m}$ , are all  
11 transmitted through the mirror or output coupler 19, as discussed  
12 before, to a beam splitter (BS) 25. The beam splitter 25 has a  
13 ZnSe substrate, is flat on both sides, is anti-reflective coated  
14 at both  $2.05 \mu\text{m}$  and  $3.01 \mu\text{m}$ , and is highly reflective at  $6.45 \mu\text{m}$   
15 for S-polarization (S-pol) at 45 degrees angle of incidence.

16       As a result, the protein band light pulses at 6 micron or  
17  $6.45 \mu\text{m}$  is reflected off the beam splitter 25 and passed through  
18 a refocusing lens 27. The refocusing lens 27 has a ZnSe  
19 substrate and is anti-reflectance coated at  $6.45 \mu\text{m}$  to refocus  
20 and pass the  $6.45 \mu\text{m}$  light pulses to a flat mirror 29 which is  
21 highly reflective at  $6.45 \mu\text{m}$ . The  $6.45 \mu\text{m}$  light pulses reflected  
22 off the flat mirror 29 are then passed to a beam combiner (BC) 31  
23 (to be discussed).

24       In order to obtain protein band light pulses at, for

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1 example, an exemplary wavelength of  $6.45 \mu\text{m}$ , the reflected  
2 protein band light pulses from the mirror 29 can be monitored by  
3 a spectrometer (not shown) while the crystal 21 is being angle-  
4 tuned until the desired wavelength is detected. As will be seen  
5 in the discussion of Fig. 2, the wavelength of the water band  
6 light pulses will change very little in relation to the protein  
7 band light as the crystal 21 is being angle-tuned.

8 Referring back to the beam splitter 25, it will be recalled  
9 that the beam splitter 25 is anti-reflective coated at both  $2.05 \mu\text{m}$   
10  $\mu\text{m}$  and  $3.01 \mu\text{m}$ . As a result, both the  $2.05 \mu\text{m}$  and  $3.01 \mu\text{m}$  light  
11 will pass through the beam splitter 25 to another beam splitter  
12 33.

13 Beam splitter 33 has a ZnSe substrate, is flat on both of  
14 its sides, is anti-reflective coated for both  $2.05 \mu\text{m}$  and  $6.45$   
15  $\mu\text{m}$ , and is highly reflective at  $3.01 \mu\text{m}$  for S-polarization (S-  
16 pol) at 45 degrees angle of incidence. As a result, any residual  
17  $2.05 \mu\text{m}$  light and any residual  $6.45 \mu\text{m}$  light will pass through  
18 the beam splitter 33 and be dissipated by an exemplary carbon  
19 beam stop 35. On the other hand, the water band light pulses at  
20 3 microns or  $3.01 \mu\text{m}$  light pulses are reflected off the beam  
21 splitter 33 and passed through a refocusing lens 37. The  
22 refocusing lens 37 for the  $3.01 \mu\text{m}$  light has a ZnSe substrate and  
23 is anti-reflectance coated at  $3.01 \mu\text{m}$  to refocus and pass the  
24  $3.01 \mu\text{m}$  light pulses to an optical delay line 39 comprised of

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1 opposing flat mirrors 41 and 43.

2       It should be recalled at this time that the dual wavelength  
3 surgical laser system of the invention simultaneously produces  
4 two different wavelengths to enable independent irradiations into  
5 the water absorption band and the protein absorption band of  
6 tissue during laser surgery. The irradiation into the protein  
7 band softens the mechanical structure of the tissue, while the  
8 water irradiation produces what is called a "thermal explosion"  
9 of the tissue to push the tissue out. However, it is important  
10 to allow some time for thermal relaxation of the mechanical  
11 structure once it has been excited by a protein band light pulse  
12 before an associated water band light pulse is applied. This is  
13 accomplished by introducing a time delay between the protein band  
14 light pulse and its associated water band light pulse.

15       It has been discussed above that the protein band light  
16 pulse at 6.45  $\mu\text{m}$  was developed and applied to the beam combiner  
17 31, and that the water band light at 3.01  $\mu\text{m}$  was simultaneously  
18 developed and applied to the optical delay line 39. It is the  
19 delay line 39 which will provide the optimum delay to the water  
20 band light pulse after the protein band light pulse has been  
21 applied to start softening the protein absorption band in the  
22 tissue or mechanical structure before the delayed water band  
23 light pulse is applied to the water absorption band in the tissue  
24 to dislodge the weakened mechanical structure.

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1           Each of the flat mirrors 41 and 43 is highly reflective at  
2   3.01  $\mu\text{m}$ . The water band light from the lens 37 strikes one end of  
3   the mirror 43 and bounces back and forth between the mirrors 41  
4   and 43 before exiting the delay line 39 from the mirror 43 and  
5   traveling to an adjustable attenuator 49 disposed in the water  
6   absorption line or beam path of the exiting delayed 3  $\mu\text{m}$  or 3.01  
7    $\mu\text{m}$  water band light pulses.

8           The mirror 43 is mounted on a translation stage 45 which is  
9   moved in the directions of the double arrows 47 by, for example,  
10   a screw (not shown) or electric motor (not shown) to change the  
11   total optical delay time to a desired optical delay by shortening  
12   or lengthening the optical path between the mirrors 41 and 43.

13           The adjustable attenuator comprises a half wave plate (not  
14   shown) for a wavelength of 3.01  $\mu\text{m}$  followed by a linear polarizer  
15   (not shown). Both of the half wave plate and polarizer  
16   components are anti-reflective coated at 3.01  $\mu\text{m}$  and may be  
17   obtained from any competent IR coating house. The half wave  
18   plate is mounted on a simple rotator (not shown). The attenuation  
19   of the adjustable attenuator can be adjusted by changing the  
20   rotational position of the attenuator by means of the simple  
21   rotator, as indicated by the double arrows 51.

22           The adjustable attenuator 49 is needed in order to account  
23   for the different requirements for the different types of tissue  
24   on which laser surgery can be performed. The amplitude of the

1 delayed water band light pulse can be attenuated by the  
2 adjustable attenuator 49 to obtain a different ratio of water  
3 absorption light to protein absorption light. This ratio is  
4 important because of the medical requirement for minimal invasive  
5 surgery. It is desirable to inflict the least amount of  
6 collateral damage to the human body during laser surgery. So it  
7 is highly desirable to use the absolute lowest amount of laser  
8 energy that can be used at the water band wavelength because it  
9 is this wavelength that destroys the tissue undergoing laser  
10 surgery.

11 A resultant sequence of attenuated, delayed water band light  
12 pulses at  $3.01 \mu\text{m}$  is applied from the attenuator 49 to the beam  
13 combiner 31. It should be recalled that a sequence of undelayed  
14 protein band light pulses at  $6.45 \mu\text{m}$  is also being applied to the  
15 beam combiner 31. As a consequence, the beam combiner 31  
16 combines the sequence of delayed water band light pulses with the  
17 sequence of undelayed protein band light pulses to develop a  
18 sequence of pairs of different light pulses, with each pair  
19 comprised of a protein band light pulse followed by a water band  
20 light pulse. This sequence of pairs of protein band and water  
21 band light pulses are then fed into a fiber delivery system (FDS)  
22 (not shown) for a subsequent surgical application.

23 Fig. 2 shows angle tuning of the  $\text{AgGaSe}_2$  OPO 13 pumped by  
24 the  $2.05 \mu\text{m}$  output of the pump laser 11 of Fig. 1. As mentioned

1 before, the AgGaSe<sub>2</sub> crystal 21 is mounted on the rotation stage  
2 23 of Fig. 1 and is angle-tuned by rotating the rotation stage 23  
3 to a desired angle.

4 The diagram of Fig. 2 is known as a Type I Tuning Curve for  
5 the AgGaSe<sub>2</sub> OPO 13 utilized in the exemplary dual wavelength  
6 surgical laser system of Fig. 1. The horizontal axis represents  
7 the phasematching angle in degrees, while the vertical axis  
8 represents the wavelengths that are developed at the output of  
9 the AgGaSe<sub>2</sub> OPO 13 when the AgGaSe<sub>2</sub> crystal 21 is pumped by the  
10 2.05 μm output of the pump laser 11 of Fig. 1. Vertical line 53  
11 shows that for any given angle determined by the rotation of the  
12 rotation stage 23 Fig. 1 and for a particular pump wavelength,  
13 two wavelengths are selected to be outputted from the OPO 13.

14 More specifically, as shown by vertical line 53 in Fig. 2,  
15 when the AgGaSe<sub>2</sub> crystal 21 is rotated by the rotation stage 23  
16 to a phase matching angle of 47.3 degrees and is pumped by the  
17 2.05 μm pump beam, the AgGaSe<sub>2</sub> OPO 13 will produce pulses of  
18 light (or protein band light or an OPO signal line) at 6.45 μm in  
19 a protein absorption band of the tissue, as shown in an upper  
20 portion 55 of the tuning curve of Fig. 2. In addition, the OPO  
21 13 will also produce pulses of light (or light band light or an  
22 OPO idler line) at 3.01 μm in a water absorption band of the  
23 tissue, as shown in a lower portion 57 of the tuning curve of  
24 Fig. 2. Therefore, both of the output protein and water

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1 absorption band wavelengths of the crystal 21 are determined when  
2 the crystal 21 is angle-tuned to a particular angle and pumped at  
3 a particular pump wavelength. Thus, in this example, if the  
4 phasematching angle were changed to about 47.5 degrees, the OPO  
5 13 would develop protein absorption band light at around 6.3  $\mu\text{m}$   
6 and water absorption band light around 3.2  $\mu\text{m}$ .

7 It should be noted at this time that, as the crystal 21 in  
8 Fig. 1 is angle-tuned by rotating the rotation stage 23 to a  
9 different phase matching angle, the wavelength of the water band  
10 light 57 shown in Fig. 2 hardly changes because of the small  
11 slope of the water band light 57. On the other hand, the  
12 wavelength of the protein band light changes quite a bit as the  
13 crystal 21 tuned, particularly at the higher end of the waveform  
14 of the protein band light 55, because of the steep slope of  
15 protein band light 55. Thus, the angle-tuning of the crystal 21  
16 can produce only a small change in the wavelength of the water  
17 band light 57, but a relatively large change in the wavelength of  
18 the protein band light 55.

19 Fig. 3 is a graph illustrating the protein and water  
20 absorption lines from the OPO 13 of Fig. 1 for one exemplary  
21 tissue type, namely neural tissue, and with the tuning angle of  
22 47.3 degrees shown in Fig.2. The horizontal axis is shown in  
23 reciprocal centimeters or wavenumbers.

24 The exemplary waterband or water absorption band at around

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1 3.01  $\mu\text{m}$  is shown by an arrow 59. This water band of absorption  
2 59 shown in Fig. 3 is quite broad. Therefore, as discussed  
3 above, as the crystal 21 of Fig. 1 is angle-tuned, the wavelength  
4 of the water band light 59 would not move out of this broad water  
5 band light 59 unless the crystal 21 is tuned very far away. It  
6 should also be noted that, as shown in Fig. 3, there is a  
7 relatively large ratio between the water tissue absorption in the  
8 3 micron region (around 3.02  $\mu\text{m}$ ) and the protein tissue  
9 absorption in the 6 micron region (around 6.45  $\mu\text{m}$ ). Different  
10 types of tissue have a different ratio of hydration. This  
11 provides the reason why it is important to be able to adjust the  
12 ratio of the water band light to the protein band light by being  
13 able to attenuate the water band light, as discussed before.

14 The exemplary protein absorption band at around 6.45  $\mu\text{m}$  is  
15 shown by an arrow 61 in an inset 63. The inset 63 shows a  
16 decomposition of the tissue into component parts due to proteins  
17 and water. So this is a water band bending mode. That is, the  
18 protein absorption bands are moving around. More particularly,  
19 inset 63 is an expanded view of of a portion of the graph of Fig.  
20 3 with three overlapping absorption bands. Of these three  
21 overlapping bands one is a water absorption band and the other  
22 two are protein absorption bands. Since the crystal 21 is  
23 tunable, the OPO 13 can be tuned to produce a protein absorption  
24 band which does not have any water content.

1           It should also be noted that the OPO 13 produces a protein  
2 absorption band which has a bandwidth of about 5 wavenumbers,  
3 whereas each of the three overlapping absorption bands in the  
4 insert 6351 is about 100 wavenumbers broad. Therefore, the  
5 unrestricted protein absorption band of the OPO 13 has adequate  
6 wavelength resolution and is adequately narrow to select one of  
7 these protein absorption bands in inset 63.

8           Fig. 4 is a graph showing the spectral output of the  
9 exemplary AgGaSe<sub>2</sub> OPO 13 of Fig. 1. The graph in Fig. 4 shows  
10 that the simple OPO 13 of Fig. 1 has a sufficiently narrow  
11 bandwidth that operates very well to produce the desired protein  
12 and water absorption bands in response to the selected pump  
13 pulses from the pump laser 11 of Fig. 1 without requiring any  
14 linewidth restriction.

15           Therefore, what has been described in a preferred embodiment  
16 of the invention is a dual wavelength surgical laser system  
17 comprising: a pump laser for emitting pump laser pulses of light  
18 at a preselected pump wavelength; an optical parametric  
19 oscillator responsive to each pump pulse from the pump laser for  
20 producing a first wavelength pulse of light in a water absorption  
21 band of the tissue and a second wavelength pulse of light in a  
22 protein absorption band of the tissue; a first set of optics for  
23 only passing therethrough each first wavelength pulse from the  
24 optical parametric oscillator; an optical delay line for

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1     delaying each first wavelength pulse from the first set of optics  
2     by a predetermined period of time; a second set of optics for  
3     only passing therethrough each second wavelength pulse from the  
4     optical parametric oscillator; and a beam combiner for combining  
5     each second wavelength pulse with the following delayed first  
6     wavelength pulse to form a stream of consecutive second and  
7     delayed first pulse pairs for application to the tissue.

8             It should therefore readily be understood that many  
9     modifications and variations of the present invention are  
10    possible within the purview of the claimed invention. It is  
11    therefore to be understood that,

12             the invention may be practiced otherwise than as  
13    specifically described.

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ABSTRACT

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A dual wavelength surgical laser system for performing laser surgery on living tissue with a minimum amount of collateral tissue damage is disclosed. The dual wavelength surgical laser system comprises: a pump laser for emitting pump laser pulses of light at a preselected pump wavelength; an optical parametric oscillator responsive to each pump pulse from the pump laser for producing a first wavelength pulse of light in a water absorption band of the tissue and a second wavelength pulse of light in a protein absorption band of the tissue; a first set of optics for only passing therethrough each first wavelength pulse from the optical parametric oscillator; an optical delay line for delaying each first wavelength pulse from the first set of optics by a predetermined period of time; a second set of optics for only passing therethrough each second wavelength pulse from the optical parametric oscillator; and a beam combiner for combining each second wavelength pulse with the following delayed first wavelength pulse to form a stream of consecutive second and delayed first pulse pairs for application to the tissue.

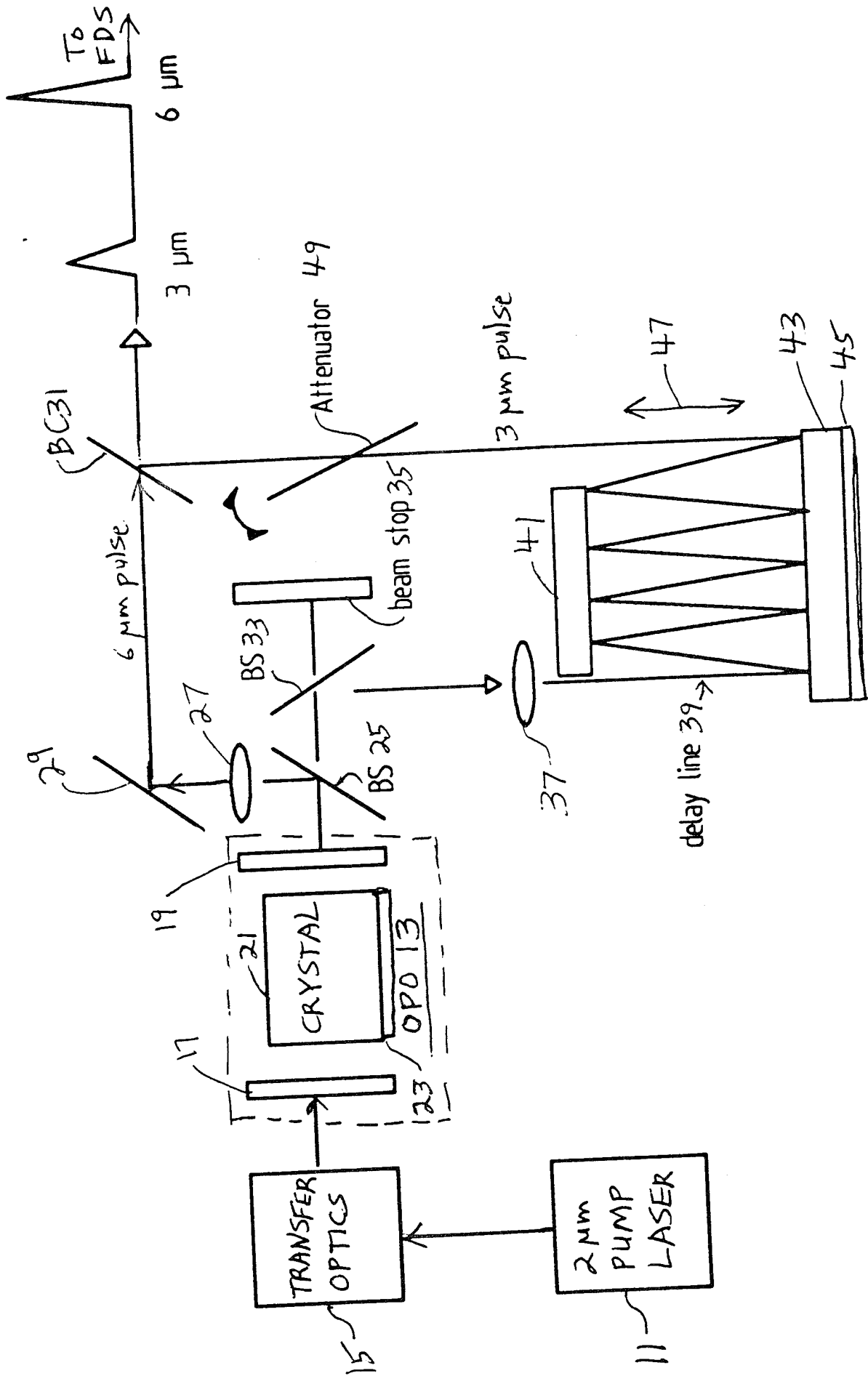
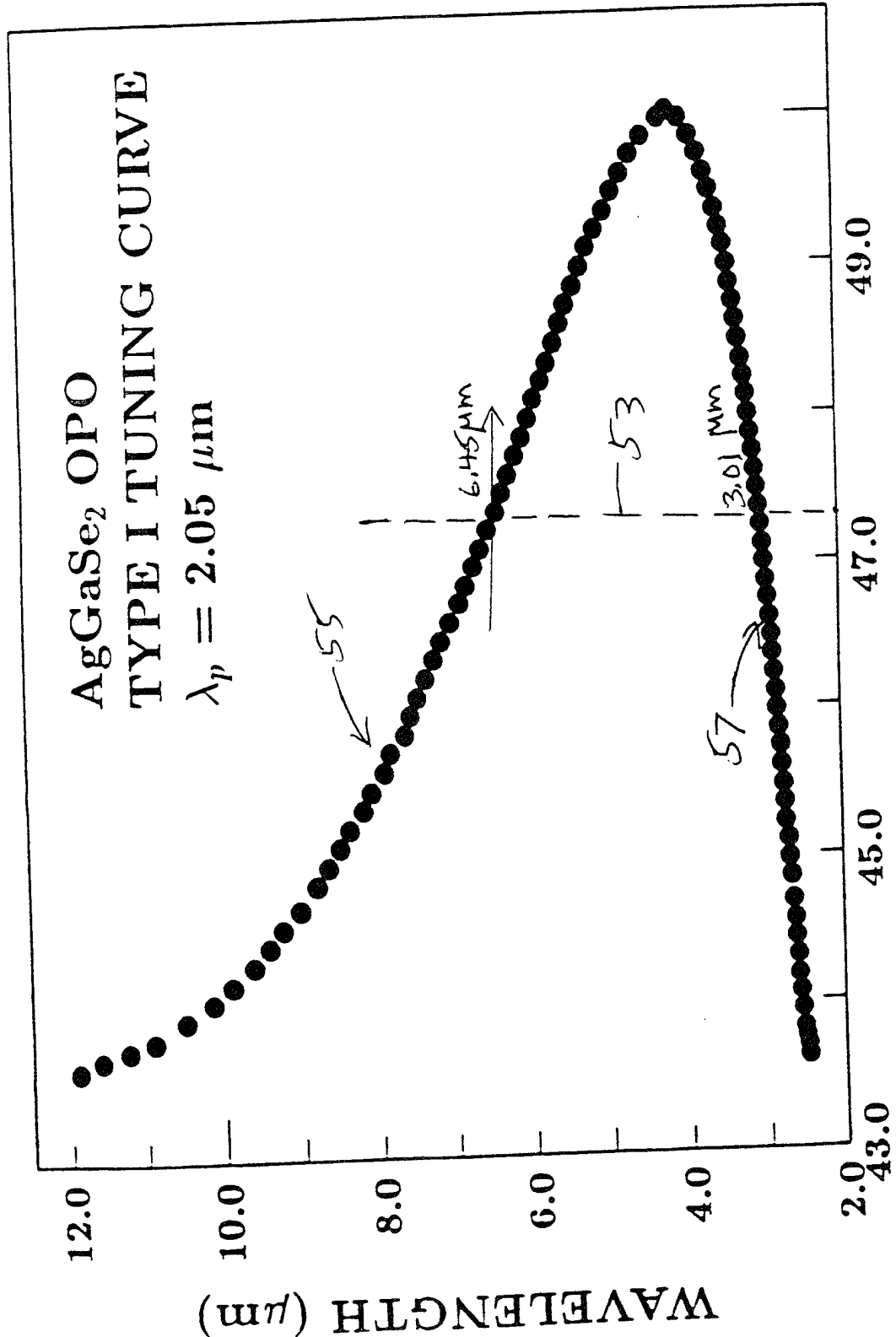


FIG. 1



PHASEMATCHING ANGLE (degrees)

FIG 2

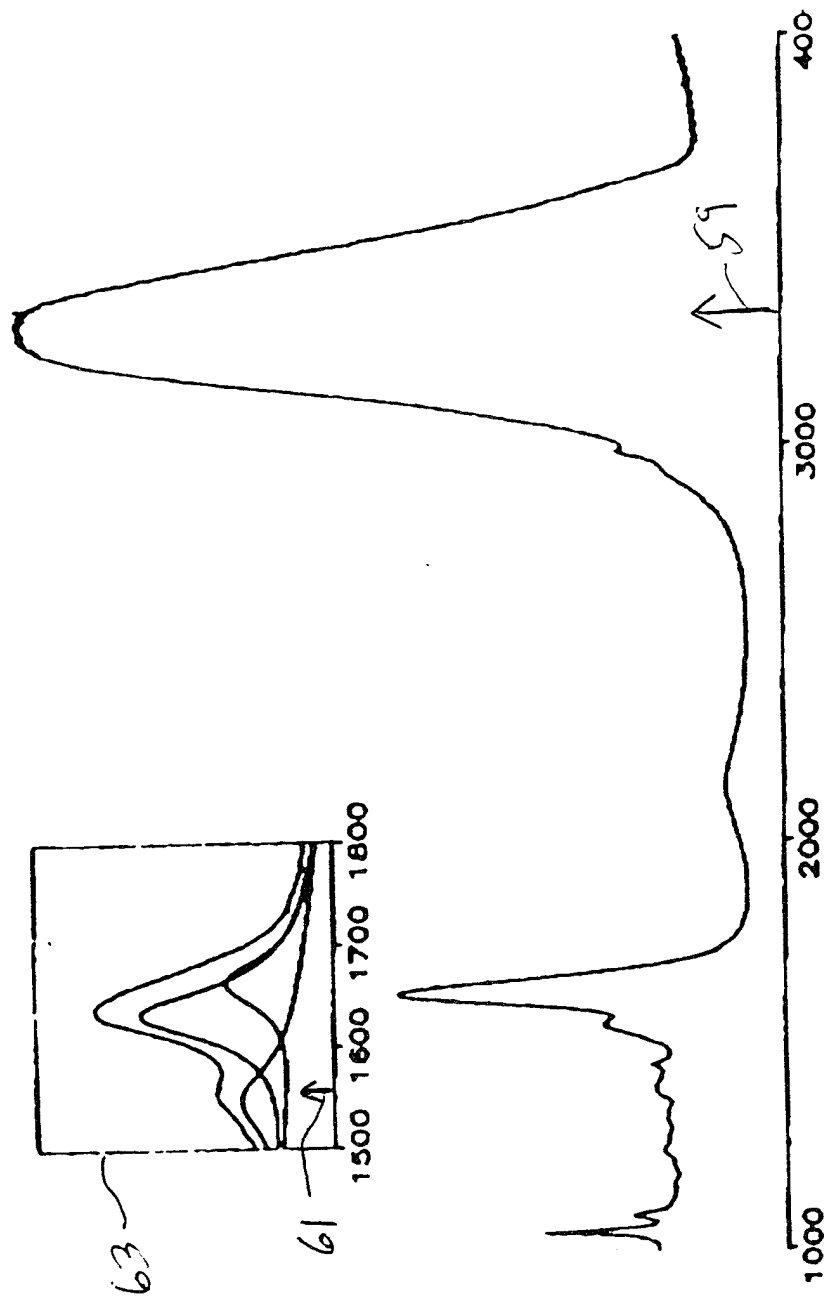


FIG. 3

# Spectral output of AgGaSe<sub>2</sub> OPO

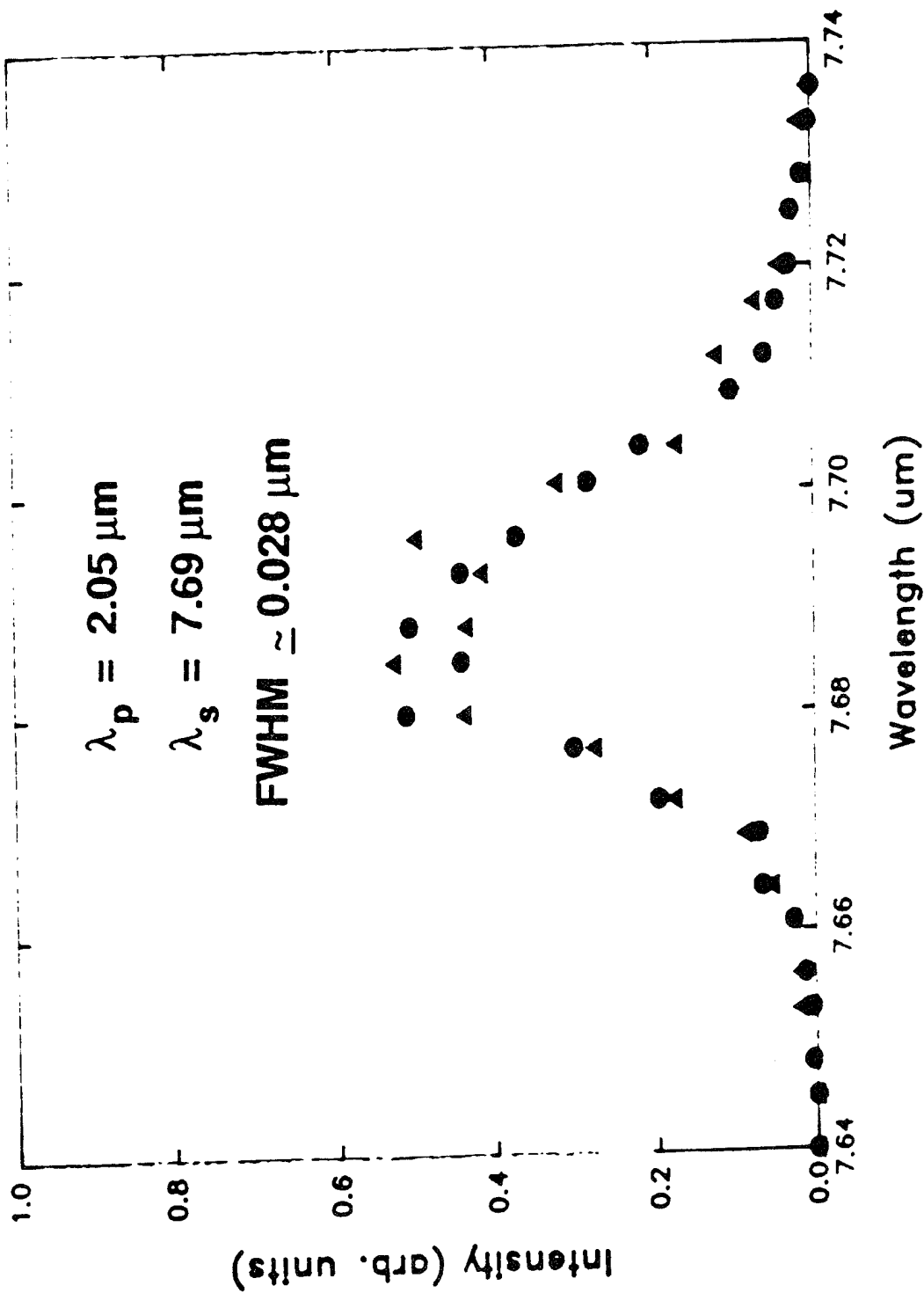


FIG. 4