

## **Optical Bandwidth Meter for Very Narrow Bandwidth Laser Emitted Light**

### **RELATED APPLICATION**

This application is related to an application entitled METHOD AND  
5 APPARATUS FOR MEASURING BANDWIDTH OF AN OPTICAL OUTPUT  
OF A LASER assigned to the assignee of the present application and filed on the  
same day as this application (Attorney Docket No. 2003-0056-01), the disclosure of  
which is hereby incorporated by reference.

### **FIELD OF THE INVENTION**

The present invention relates to the detection of laser emitted light bandwidth  
for lasers emitting light at very narrow bandwidths, e.g., sub-pico-meter bandwidths  
with error tolerances of hundredths of pico-meters and below. More generally the  
present invention relates to the accurate estimation of the bandwidth of an optical  
15 source using, e.g., interferometric or dispersive instruments ("spectrometers") whose  
impulse response functions have bandwidth generally comparable to or larger than  
that of the source being measured.

### **BACKGROUND OF THE INVENTION**

20 Spectrometers are well known for use in the measurement of both  
wavelength and bandwidth of light sources, e.g., lasers. The output of such a  
bandwidth meter for example is actually the result of measurement, e.g., utilizing a  
photo diode array ("PDA") as is well known in the art to measure, e.g., the  
bandwidth of an output from the spectrometer optics, which is actually a convolution  
25 of the actual bandwidth of the light spectrum input into the bandwidth meter (the  
actual bandwidth to be measured) and the response function of the bandwidth meter.  
The bandwidth meter has its own response function that modifies the spectrum being  
measured during the measurement of the bandwidth.

If this were process could be accurately represented as the mathematical  
30 convolution of two analytic Gaussian or two analytic Lorentzian spectra, the  
bandwidth of the laser light could be determined from the response of the meter with

simple algebraic equations. However, the output spectra of most lasers are not in such simple analytical form nor are the response functions of, e.g., optical dispersive bandwidth detecting instruments, e.g., etalons.

The spectrometer optics, particularly an optical interferometer, e.g., an etalon, as a finite finesse or “Q” which is calculated by the formula  $f = (\pi r^{1/2}) / (1-r)$ , where r is the reflectivity of the juxtaposed partially reflective mirrors within the etalon. Etalons have a property also of a free spectral range (“FSR”) which is found by the equation  $FSR = \lambda^2 / (2 * n * d)$ , where  $\lambda$  is wavelength, n is the index of refraction of the material separating the juxtaposed reflective surfaces of the partially reflective mirrors and d is distance between the two. A factor known as Etalon Resolution (“ER”), in bandwidth, is found by the equation  $ER = FRS / \text{finesse}$ . A reasonable approximation, but not an exact representation of this is a Lorentzian shaped curve. Currently in bandwidth meters, e.g., for lasers, e.g., with bandwidth in the pico-meter range the error can usually be dealt with a an offset or delta function using some calibration constant because the bandpass of, e.g., an etalon being used in the bandwidth meter is relatively much broader than the bandwidth of the laser output being measured.

However, as the requirements for more narrow critical dimension line features on, e.g. Ultra-Large-Scale-Integration (“ULSI”) integrated circuit fabrication are ever increasing (decreasing critical dimensions), the demand for pure laser light at a particular very narrow wavelength (Deep Ultraviolet – “DUV” and Extreme Ultraviolet – “EUV”) and with purity defined by very narrowly controlled bandwidth around the center wavelength, the etalons used for such measurements are becoming much closer in response function to the bandwidth of the laser light itself, the traditional delta function no longer applies. For, example on a recently released product of Cymer, Inc., the owner by assignment of the present application, the XLA 100, an on-board bandwidth meter utilized an etalon with a bandpass of about 0.12 pm and the laser provided an output generally between about 0.1 pm and 0.18 pm, discounting bandwidth resonance. The convolution then distorts the measured laser light, e.g., in bandwidth, in ways that now make or will soon make measurements of, e.g., the full width half maximum (“FWHM”) insufficiently

accurate for proper input into controllers used to modify the operation of the laser as the wavelength and/or bandwidth move away from desired targets or out of desired ranges. This is in part at least due to bleed in of energy from the laser light being measured into the etalon output spectrum. This bleeding problem can be even more  
5 exaggerated when it is the bandpass of the etalon that is broader than the bandwidth of the measured input light and both are close in value, since this causes the bandpass of the etalon to be even more influenced (distorted) by the measured laser light spectrum.

Currently the output of the bandwidth meter used as an indication of the  
10 bandwidth of the measured laser light bandwidth is, e.g., a measure of a fringe width, e.g., at FWHM of a fringe produced by the etalon optics less some constant error value, e.g., ER, otherwise known as Etalon Correction ("EC"). As noted, however, this is not exact unless the distribution of the output of the etalon is Lorentzian, which it is not.

15 To exacerbate the problem, even if initially measurements could be made of ER that were satisfactory to keep a bandwidth meter on a given laser system within specs when initially manufactured, it has been found that etalons change over time as laser bandwidth meter optics, that the variable conditions of the operation of the laser over time influence the actual ER, and further, when spares are at issue, the  
20 bandwidth meter cannot be calibrated at the factory with the same laser that it will become the bandwidth meter for in the field, and the calibrating system is too bid and too sensitive to be moving around to customer sites to fit the bandwidth meter to the customer laser and too expensive to maintain one at each customer site.

If that were not enough, there is a growing belief in the industry, e.g., for  
25 semiconductor manufacturing at sub-0.1 micron line width manufacturing that the real measure of bandwidth for proper control of purity is, e.g., E95, which is a measure of the integrated energy within the laser output spectrum that constituted some percentage, in this case 95% for E95 of the total energy in the spectrum, limited by some finite boundary on the roll off of the energy on either side of the  
30 peak(s) to zero at  $\pm$  infinity, typically about 10pm.

Applicant has also discovered that there is a variation of FWHM and E95 dependant upon the duty cycle at which a pulsed laser is driven which too large to be accounted for at initial calibration within ER for sub-pm lasers and also varies laser to laser and over laser life.

5           Bandwidth detectors (wave meters), e.g., spectrometers based on, e.g., dispersive optical elements or optical interference phenomena are well-known instruments commonly applied for the measurement of absolute wavelength and bandwidth of light sources. When employed as a bandwidth-measuring tool (“bandwidth detector/meter”), the effect of the finite impulse response of the  
10   spectrometer must be considered in determining the bandwidth of the source being measured. For the purpose of this application, “bandwidth” may refer to any number of metrics or mathematical constructions, such as full-width of the spectrum at half-maximum intensity (“FWHM”), full width at some other percentage of the maximum (“FWXM”), width of 95%-enclosed intensity integral (“I95%” or  
15   “E95%”), or some other percentage of the energy enclosed in the spectrum portion (“IX%” or “EX%”), etc. An accurate knowledge of the bandwidth of an optical source is very important for many scientific and industrial applications, for example in spectroscopy of liquids or gases, critical dimension control in semiconductor photolithography, etc.

20           In very simple cases, for example when the spectrum of the source and the spectrometer impulse response are accurately represented both by analytic Gaussian or both by analytic Lorentzian functions, the effect of the spectrometer impulse response can be easily accounted for using simple algebraic equations for most bandwidth metrics. The output spectra of most optical sources, e.g. lasers, do not,  
25   however, have such a simple form, and the impulse response of the spectrometer may be similarly complex and/or unknown, or may vary over time or in varying operating environments. Further, the detailed shape of the spectrum of the optical source itself may change over time or with changing operating conditions.

          A common method employed to surmount these obstacles is to employ a  
30   spectrometer whose impulse response has a bandwidth so narrow in comparison to the expected bandwidth of the source to be measured that in the convolution of the

spectrum being measured and the impulse response of the bandwidth detector optics, the influence of the bandwidth detector optics may be considered to be negligible. That is, the spectrometer impulse response may be approximated by a simple mathematical delta-function. However, it is not always practical or even possible to  
5 obtain a spectrometer with such a narrow-bandwidth impulse response, particularly when it must be narrow in comparison to a source such as a laser which itself may be extremely narrow (tens of femtometers or less on a wavelength scale).

A second somewhat more sophisticated method commonly used approximates the spectrometer impulse response function and the source spectrum  
10 with analytic functions (e.g. of a Lorentzian, Gaussian, or mixed type) for which the effects of convolution within the spectrometer can be expressed in simple mathematical terms. As noted above, this is not necessarily a good approximation, and often fails or becomes very difficult to implement dependably for certain types of bandwidth metrics. Calculation of integral bandwidth metrics such as I95% can  
15 be inaccurate or very computationally intensive using this technique.

As an illustration of second method and its shortcomings, a recently released product of the assignee of the present application, the XLA-100, contains an onboard bandwidth meter employing a single etalon with a FWHM bandpass of about 0.12 picometer (pm) that is used to interrogate the output of a deep-ultraviolet  
20 excimer laser light source having an average typical FWHM bandwidth of about 0.17 pm. The above approximation is made in which both the laser and the etalon spectrometer are assumed to have an analytic Lorentzian spectral shape; therefore, the FWHM output of the instrument is found mathematically to be simply the sum of the FWHMs of the laser source and the etalon spectrometer impulse response. In  
25 this approximation, then, the laser bandwidth is estimated by the FWHM output of the instrument, minus the FWHM of the etalon spectrometer impulse response (determined in independent measurements). However, because the ratio of the FWHM bandwidths of the source spectrum and impulse response function is close to unity, this method may lose accuracy in the event that the shape of the laser  
30 spectrum deviates too far from an approximately-Lorentzian shape. For example, a narrowing of the central spectral peak of the source spectrum with a concomitant

increase in energy in the near wings of the actual laser spectrum can result in an over-estimation of the FWHM bandwidth in this approximation.

In addition, if the detailed shape of the laser spectrum is constant, the offset subtracted in this example may be adjusted to compensate. However, if the shape of the laser spectrum changes, e.g., with operating conditions, with system alignment, or over the lifetime of the product, even this compensation will not remain accurate. Also at issues is the complicating possibility that in a manufacturing setting, the etalon spectrometer may be tested and offset-calibrated on one laser, but is ultimately installed on another that has a slightly different spectral shape, e.g., as a replacement part. In this case the calibration itself may be in error.

There is a need, therefore for a sub-pm (approaching femto-meter “fm”) bandwidth meter that can be calibrated in such a way as to be portable laser to laser and to respond to laser property changes and laser operation changes, including over the lifetime of the laser. The need exists to provide for more accurate measurement, e.g., through estimation of the enclosed energy parameters, e.g., E95%, which are increasingly being demanded by users of the highly pure light produced, e.g., by lasers as described above. In order to support very high pulse repetition rates and pulse to pulse corrections the need must also be satisfied with a solution that is computationally simple to execute, i.e., requiring a minimal number of instructions and thus computation time in cycles of whatever processor is utilized.

## SUMMARY OF THE INVENTION

A method and apparatus for measuring bandwidth of light emitted from a laser is disclosed which may comprise: a first and second wavelength sensitive optical bandwidth detectors providing, respectively, an output representative of a first parameter indicative of the bandwidth of the emitted light as measured respectively by the first and second bandwidth detectors, and an actual bandwidth calculation apparatus adapted to utilize these two outputs as part of a multivariable linear equation employing predetermined calibration variables specific to either the first or the second bandwidth detector, to calculate a first actual bandwidth parameter or a second actual bandwidth parameter. The first actual bandwidth

parameter may be a spectrum full width at some percent of the maximum ("FWXM"), and the second actual bandwidth parameter may be a portion containing some percentage of the energy ("EX"). The first and second bandwidth detectors may an etalon and the outputs may be representative of a fringe width of a fringe of an optical output of the respective etalon at FWXM. The precomputed calibration variables may be derived from respective three dimensional plots representing, respectively, detector outputs in relation to a calibrating input light with known values of the first and second actual bandwidth parameters, which may be FWXM and EX. The first/second three dimensional plot may provide a solution:

(first/second output) = (a/d \* (calibrating input light known value of FWXM)) + (b/e \* (calibrating input light known value of EX) + c/f; and the actual bandwidth calculation apparatus may use the derived equation: (first actual bandwidth parameter) = ((b \* (second output)) - (e \* (first output)) + ce - bf) / (bd - ae), or the equation: (second actual bandwidth parameter) = ((a \* (second output)) - (d \* (first output)) + cd - af) / (ae - bd). FWXM may be FWHM and EX may be E95. The transfer function of the first optical bandwidth detector may be selected to be much more sensitive to FWXM than to EX and the transfer function of the second optical bandwidth detector may be selected to be much more sensitive to EX than to FWXM.

## BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 shows a representative example of a three dimensional plot of the response of a laser bandwidth meter of the prior art to laser light varying by known amounts in FWHM and E95, as measured by a calibrating source of laser light which is relatively precisely adjustable in FWHM and E95 utilizing a constant ER;

Fig. 2 shows a representative plot of the type shown in Fig. 1 for a bandwidth meter according to the present invention having, e.g., an etalon that is relatively more sensitive to change in FWHM than to change in E95;

Fig. 3 shows a representative plot of the type shown in Fig. 1 for a bandwidth meter according to the present invention having, e.g., an etalon that is relatively more sensitive to change in E95 than to FWHM;

Fig. 4, there is shown a schematic block diagram of a bandwidth meter 10 according to an embodiment of the present invention.

Fig. 5 shows a plot indicating the superior tracking of actual bandwidth utilizing the present invention;

5 Fig. 6 shows the superiority of the tracking error utilizing the present invention;

Fig. 7 illustrates the simulated tracking of E95 utilizing a bandwidth meter made according to an embodiment of the present invention;

10 Fig. 8 illustrates the tracking error of a simulated bandwidth meter made according to an embodiment of the present invention;

Fig. 9 shows a normalized convolved fringe-width excess output for various input spectra

Fig. 10 shows a plane approximation of the simulated etalon outputs shown in Fig. 9.

## 15 DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Turning now to Fig. 1 there is shown a three dimensional plot of the response of a bandwidth meter (wave meter) having, e.g., an ultra low wedge etalon, e.g., as made by manufactured by Coherent, and utilizing the prior art correction ER, as the values of FWHM and E95 are varied as measured utilizing a very accurate  
20 spectrometer, e.g., a grating spectrometer, e.g. as manufactured by Laser Technik Brelin ("LTB").

It can be seen that the etalon wave meter using the prior art ER exhibits roughly the same response to both E95 and to FWHM, both in pico-meters. The illustrated correlation gridding response when smoothed out by any of a number of  
25 well known fitting techniques, such as the Levenburg Marquardt multivariable minimization algorithm, exhibits a response function  $A \cdot x + B \cdot y + C$  with  $A = 0.64495 \pm 0.0166$ , and  $B = 0.20797 \pm 0.01105$  and  $C = 0.22983 \pm 0.00719$ , of which in the prior art the A term representative of change in FWHM and the C term representative of some constant offset are utilized in setting ER for any given wave  
30 meter at the factory during the calibration process in manufacturing. The B term is not entirely ignored, but is averaged and incorporated into the constant C.

Turning now to Fig. 2 three is shown a three dimensional plot of a simulated bandwidth meter (wave meter) that utilizes, e.g., an optical bandwidth measuring device, e.g., an interferometer, e.g. and etalon interferometer, which, e.g., detects bandwidth of the input laser light by detecting the FWHM of a fringe created by the etalon projected optically onto an array of photo-diodes ("PDA"). The response indicates that the bandwidth meter is relatively more sensitive to change in FWHM than to change in E95. The response equation derived from the smoothed out plot shown in Fig. 2 results in  $A = 0.66704 \pm 0.00221$  and  $B = 0.8951 \pm 0.00079$  and  $C = 0.10172 \pm 0.00039$ .

Turning now to Fig. 3 there is shown a three dimensional plot of a simulated bandwidth meter (wave meter) that utilizes, e.g., an optical bandwidth measuring device, e.g., an interferometer, e.g. and etalon interferometer, which, e.g., detects bandwidth of the input laser light by detecting the FWHM of a fringe created by the etalon projected optically onto an array of photo-diodes ("PDA"). The simulation utilizes a 0.7 pm/20 pixel bandpass. The response indicates that the bandwidth meter is relatively more sensitive to change in E95 than to FWHM. The response equation derived from the smoothed out plot shown in Fig. 3 results in  $A = 0.14483 \pm 0.00114$  and  $B = 0.16575 \pm 0.00041$  and  $C = 0.67263 \pm 0.0002$ .

Applicant has discovered that taking two such response plots for each of two different bandwidth meters, e.g., one relatively more sensitive to change in E95 and one relatively more sensitive to change in FWHM, i.e., with different finesse in the case of bandwidth meters employing etalon optics to measure the bandwidth, and using the second values of A, B and C, noted above as D, E and F in two separate linear equations:

(first output, e.g., etalon 1 fringe width value) =  $(a * (\text{calibrating input light known value of the full width at some percent of the maximum within the full width of the spectrum, e.g., FWXM})) + (b * (\text{calibrating input light known value of the width between two points on the spectrum defining a content of the spectrum containing some percentage of the energy of the full spectrum, e.g., EX})) + c$ ; and  
 (second output, e.g., etalon 2 fringe width value) =  $(a * (\text{calibrating input light known value of the full width at some percent of the maximum within the full$

width of the spectrum, e.g., FWXM)) + (b \* (calibrating input light known value of the width between two points on the spectrum defining a content of the spectrum containing some percentage of the energy of the full spectrum, e.g., EX) + c; then the actual bandwidth calculation apparatus can be programmed to solve the derived equation:

$$\text{(first actual bandwidth parameter, e.g., FWXM)} = ((b * (\text{second output, e.g., etalon 2 fringe width value})) - (e * (\text{first output, e.g., etalon 1 fringe width value})) + ce - bf) / (bd - ae),$$

or the equation:

$$\text{(second actual bandwidth parameter, e.g., EX)} = ((a * (\text{second output, e.g., etalon 2 fringe width value})) - (d * (\text{first output, e.g., etalon 1 fringe width value})) + cd - af) / (ae - bd).$$

In the more specific case where FWXM is the FWHM value and EX is E95 and X is the output of the first etalon PDA and X' is the output of the second etalon PDA, then  $X = a * \text{FWHM} + b * \text{E95} + c$  and  $X' = d * \text{FWHM} + e * \text{E95} + f$ , and therefore:

$$\begin{aligned} \text{FWHM} &= (b * X' - e * X + ce - bf) / (bd - ae), \text{ and} \\ \text{E95} &= (a * X' - d * X + cd - af) / (ae - bd) \end{aligned}$$

Therefore, each of the bandwidth meters can be calibrated at the factory at time of manufacture and combined into a bandwidth meter, e.g., to operate in parallel and the controller, discussed below, can be programmed to utilize the two outputs with the previously determined calibration values for each bandwidth meter, e.g., a – f, and the two outputs measuring the bandwidth of the same laser output to solve for either or both of FWXM and EX. That is, full width at some percent of the maximum, e.g., FWHM or FW75%M, and/or EX, i.e., the width of the spectrum within which some percentage of the total energy is contained, e.g., E95% (“E95”) or E97% or E93%, can be solved for by storing the respective coefficients in memory available to the processor and providing to the processor actual outputs from the respective bandwidth meters, e.g., etalons during actual laser operation measuring the light output in the two respective etalons in parallel to provide the inputs to the controller. It will be understood that if other than the current standard FWHM

and/or E95 is to be measured and calibrated for at the factory then such other value(s) will be the ones against which the output, e.g., etalon fringe measurement, will be plotted as discussed above to derive the values of  $a - f$ .

Turning now to Fig. 4, there is shown a schematic block diagram of a bandwidth meter 10 according to an embodiment of the present invention. The bandwidth meter 10 may be set up to measure the bandwidth of a light beam 14 produced by a laser, e.g., a high pulse power excimer laser, e.g., an ArF MOPA dual chambered laser producing light at a nominal wavelength of 193.350 nm and a bandwidth of less than 0.3 pm and bandwidth accuracy requirement of  $\pm 0.02$  pm.

The laser light beam 14, which may, e.g., be utilized as the light source for, e.g., exposing photoresist through a reticle (mask work) in sub-micron fabrication of integrated circuits, micromachines, nano-technologies, or the like ("photolithography") may be split, e.g., in a beam splitter 16 which can be set to pass most of the beam 14 and reflect a small portion, e.g., less than 1% in beam 18 which can pass through a second beam splitter 20 which may be set to reflect and pass essentially identical amounts of the beam 18 in a reflected beam 22 and a passed beam 24, each of which enter a respective bandwidth meter 30, 34. The bandwidth meters 30, 34 may include an optical bandwidth measuring apparatus, e.g., an etalon for creating fringes that are indicative of the bandwidth of the light measured and an electrical circuit (not shown) e.g., a PDA for providing an analog or digital input to a controller 40 which may, e.g., be representative of the measurement of, e.g., the fringe created by, e.g., the etalon. The etalon 30 may, e.g., be selected to have nominal bandpass values of, e.g., 0.12 pm FWHM, a free spectral range of, e.g., 3pm at 193.36, for an ArF laser bandwidth measurement, and an effective finesse of  $\geq 25$ , e.g., over a 10mm aperture, and a peak transmission (ratio of the fringe peak photo-electrical signal and the input peak signal) of  $\geq 50\%$  at 193.350 nm normal incidence. The etalon 34 may be selected to have nominal bandpass values of, e.g., 0.7 pm FWHM a free spectral range of, e.g., 20 pm at 193.36, for an ArF laser bandwidth measurement, and an effective finesse of  $\geq 29$ , e.g., over a mm aperture, and a peak transmission (ratio of the fringe peak photo-electrical signal and the input peak signal) of  $\geq$  % at 193.350 nm normal incidence.

It will be understood that this type of calibration can be employed with other bandwidth measurement instruments that are susceptible to the same or similar kinds of frequency dependent response issues.

It will be understood from the above that applicant has create an optical  
5 bandwidth measuring apparatus consisting of parallel measurements of a beam of light, e.g., output from a laser at very small wavelengths and very narrow bandwidths, using e.g., two etalons of significantly differing bandpass. The two arms of the bandwidth measuring apparatus which exhibit differential sensitivity to the energy content of the wings or skirts of the spectrum being measured. The  
10 output of each of the two parallel bandwidth measuring apparatus, e.g., the FWHM values of fringes created by each respective etalon provide approximate solutions to a system of simultaneous bilinear equations that can be inverted to find a good approximation of the actual FWHM and E95% widths of the laser light being measured. The gradient of the plane, e.g., shown in Fig. 3 along the E95 axis is very  
15 sensitive to the etalon wedge, i.e., to the finesse (i.e., bandpass). Similarly the FWHM slope in Fig. 2 is larger due to the bandpass of the second etalon.

Data taken for the measurements and simulations illustrated, e.g., in Fig.'s 1 – 3 measured the FWHM and E95% with a very sensitive and highly calibrated wave meter, e.g., a grating spectrometer, e.g., as made by Laser Technik Berlin, and  
20 plots of these were made against the output of, e.g., each respective etalon measuring light from, e.g., a 7000A excimer laser and/or an XLA-100 excimer laser, each of which are products of the assignee of the present application, for sets of resonance scans with a variety of fills. Applicant collected a large sample of spectra, e.g., from an XLA-100 during pilot manufacture and obtained an  
25 approximate actual laser spectra by deconvolving using Fourier methods and calculated a response of a theoretical etalon circuit, choosing the nominal bandpass values for one etalon of 0.7 pm FWHM, 20 pm FSR and  $F=29$  and for the second etalon 0.12 pm FWHM, 3 pm FSR and  $F=25$ . Also simulated was a line center analysis module ("LAM") as appears in the assignees products, utilizing an etalon  
30 wave meter, but with a higher resolution imaging system to avoid pixel aliasing, i.e., having the same resolution of the other etalon, e.g., on like that appearing in the

assignee's products in a spectral analysis module ("SAM"), i.e., ~ 20 pixels in FWHM rather than the ~ 4 in current LAMs.

Applicant discovered that the behavior of the output of an etalon could be reasonably approximated by a plane surface resulting from the three dimensional plot. From wave meter to wave meter, however, applicant also discovered that the  
5 slope of the plot on the E95 axis was sensitive to etalon wedge (finesse). From this applicant concluded that the simultaneous equations noted above could be used with, e.g., two etalons of very different bandpass to calibrate a wave meter using parallel measurements of the bandwidth and provide a bandwidth measuring apparatus  
10 employing the precalculated calibration coefficients and the separate outputs of the two parallel wave meters, e.g., etalons with the coefficients to solve for the two unknown variables, either FWHM or E95. The two outputs, e.g., from the two etalons are connected by a linear transformation, using the precalculated coefficients, to the real FWHM and E95 values. An etalon with a narrower  
15 bandpass showed a very much larger slope in the FWHM axis than the one with the narrower bandpass, which in turn was more sensitive on the E95 axis, as shown in Fig. 3, with most of the sensitivity appearing in the constant C in the equation, reflecting the relatively broader bandpass spectrum of this second etalon.

According to the disclosed embodiment of the present invention tracking of  
20 bandwidth detectors, e.g., using FWHM portability can be improved significantly and E95 metrology on-board a high power high pulse rate narrow bandwidth excimer laser is now possible. Whether or not full width at something other than half maximum, i.e., FWXM is a better measurement and/or an energy of something other than 95% within the spectrum, i.e., EX, is or are more optimal as bandwidth  
25 measurements, e.g., for certain applications like delivering very pure light for photolithography remains to be seen. In addition the optimal choices for, e.g., the differential in bandpass for the two etalons remains to be determined. However, as discussed below with respect to Fig.'s 9 and 10 this can easily be determined to be a maximum ratio of bandpass to bandpass for each etalon that enables, e.g., the  
30 parallel etalon bandwidth detector according to an embodiment of the present

invention to function acceptably, e.g., produce an output signal that is of sufficient signal to noise ratio to be accurately measured.

Turning now to Fig. 5 there is shown an illustration of the FWHM tracking capabilities of a simulated wave meter according to an embodiment of the present invention. Turning now to Fig. 6 there is shown an illustration of the FWHM tracking error of the simulated wave meter, showing a much narrower variance around a mean much closer to 0.0 and the avoidance of outliers (way out of spec readings which seem in the current state of bandwidth detection apparatus in use on lasers today to overestimate FWHM when both FWHM and E95 are already large, i.e., when error margin is minimum. Turning now to Fig. 7 there is shown an illustration of the E95% tracking of a simulated bandwidth detection apparatus according to the present invention. Turning now to Fig. 8 there is shown an illustration of E95 tracking error for the simulated bandwidth detection apparatus according to the present invention, measured in the tens of femto-meters.

Turning Now to Fig. 9 there is shown a representation of the a normalized convolved fringe-width excess (simulated output of each of the two, e.g., optical bandwidth meters) for various input spectra compared to the actual values of input spectrum FWHM and E95. The solid lines representing the simulated output of the first detector with a relatively narrower bandpass and the dashed lines representing the simulated output of the second detector having a relatively more narrow bandpass. Turning to Fig. 10, there is shown a planarized approximation of the simulated responses shown in Fig. 9. It can be seen in Fig. 10 that the responses of the first and second detectors vary roughly linearly and have differing slopes. Fundamentally, for purposes of an embodiment of the present invention the slopes should form an angle  $\theta$  that is as large as possible, recognizing that at some point the angle  $\theta$  is so large that the  $\Delta$ fringe becomes so small relative to the fringe that signal to noise considerations come into play and interfere with the accuracy of the output. That is, e.g., as the broader bandpass measurement is made with a broader and broader bandpass, according to an embodiment of the present invention, the benefits of the present invention increase to some limiting point where the relative difference

between the bandpass of each of the two detectors in parallel causes signal to noise ratio deterioration of the accuracy of the output.

Normalized fringe-width excess means the amount by which the, e.g., FWHM of the fringe exceeds the FWHM of the impulse response of the etalon spectrometer, divided by the maximum value obtained for all the spectra in the data sample. That is, e.g.:

Normalized fringe-width excess = (FWHM Fringe - FWHM response function)/(largest of these differences)

This metric allows one to compare, e.g., the variation of the two spectrometer channel outputs on the same scale. Fig.'s 9 and 10, therefore, represent the actual output of the simulation. In this simulation, roughly 4,800 actually measured grating-spectrometer spectra from 6 different, lasers, e.g., pilot XLA-100's sold by the assignee of the present application, were deconvolved using the grating spectrometer's measured response function and a Fourier Transform method. The inspection region of each laser spectrum was 16 pm wide. This is sufficient to give a good sample of the actual spectrum of the light one would expect to come out of the lasers. These spectra were then convolved with the response functions of two simulated etalon spectrometers, including the effects of a pixelated detector, e.g., a PDA, etc. The simulated etalon spectrometers had response functions of 0.12 pm FWHM (~3 pm FSR with finesse of 25) and 0.70 pm FWHM (~20 pm FSR with finesse of 28). The data were gridded on a 69x69 matrix using a correlation method with a correlation radius of 4 for the purpose of visualization. How one chooses to grid the data affects its appearance; in the plane approximation (second plot) the lines should be perfectly straight, but they are not. This is an artifact of the gridding method used. One could likely fine tune this to make it work better in producing straighter lines. It is, however, representative of a planarized fitting, sufficient to demonstrate the concept of an embodiment of the present invention.

The term "fitting," mathematically indicates a "parametric modeling" of the fringe width data. Taking the 4,800 data points of the surface measured by the respective etalon spectrometer in simulated response to the different actual input spectra, one tries to model this data with a plane  $z=ax+by+c$ . This reduces 4,800

numbers to just 3. Going from Fig. 9 to Fig. 10 one choose, e.g., a merit function that measures the agreement between the actual data to the plane surface (, e.g., a chi-squared statistical function, utilizing, e.g.,  $\chi^2/\text{Degree of Freedom}$  ("DoF") and  $R^2$ , and then minimizing this merit function in the many dimensions to obtain the so-called "best-fit parameters" A, B, and C, using, e.g., the Levenberg-Marquardt method, which is essentially modern standard of nonlinear least-squares optimization routines, well known in the art. Those skilled in the art will understand that utilizing this technique, along with choosing an etalon response function that works with the expected laser spectral variations allows one to make this approximation where thousands of data points can be described by just three parameters. While this may not work for all possible spectral shapes, the applicant has observed that it does work very well for spectra that are relatively symmetric about a central peak.

The apparatus and method according to the described embodiment of the present invention provides overall improved predicted and actual tracking (e.g., ~ a factor of 2 reduction in FWHM error variance) and reduces the incidence of outliers in tracking error, e.g., due to actual E95 changes in the measured light beam. The present invention also gives greatly improved portability of coefficients between resonance scan calibration and operation with, e.g., variations in gas enrichment and frame-to-frame spectral variability. It also appears to offer a very reasonably accurate on-board E95 tracking (e.g.,  $\pm 0.015\text{pm}$ ) utilizing existing technology, e.g., etalons in parallel.

Those skilled in the art will appreciate that an aspect of the disclosed embodiment of the present invention is that the method and apparatus may be applied to calibrate the wave meter to provide a calculated output indicative of one bandwidth parameter, e.g., EX, where the measured parameter is not the same type of parameter, i.e., FWXM, which may be easier to more accurately detect and/or more computationally simple to compute from observable information, e.g., fringe width, e.g., at FWHM, as measured on an array of photo-sensitive diodes ("PDAs") as is well known in the art. In addition according to an embodiment of the present invention the outputs of each of the bandwidth detectors may be in, e.g., FWHM and

the output of the entire bandwidth detector may be in FWXM, something other than the width at half of the maximum. Further, the outputs of the two optical bandwidth detectors may be in FWXM, rather than in FWHM according to another embodiment of the present invention.

5        According to another embodiment of the present invention the calibration coefficients can be determined utilizing, e.g., FWXM and FWX'M, where X and X' are two different percentages of the maximum, e.g., FW75%M and FW25%M, i.e., forming the three dimensional plot as shown, e.g., in Fig. 2 with measurements of LTB DFW75%M on one horizontal axis and LTB DFW25%M on the other, as  
10       compared to the etalon fringe width measurement, also at some FWXM (or even EX if that is the response from the etalon to be ultimately utilized in measuring actual incident spectra in use of the bandwidth detector) and still be able to solve for the actual incident spectra FWXM, e.g., FWHM and EX, e.g., E95, provided that the first detector is relatively more sensitive to FWHM than to E95 and the second  
15       detector is relatively more sensitive to E95 than to FWHM.

Those skilled in the art will understand that as a generalization of an embodiment of the present invention,  $BW_1$  can be considered to be the detected bandwidth as measured by one bandwidth detector and  $BW_2$  can be considered to be the detected bandwidth as measured by the second bandwidth detector in parallel.  
20       Also  $BW_3$  can be considered to be a first bandwidth parameter of the incident beam, e.g., the output of an excimer laser, e.g., a deep ultraviolet ("DUV") laser or an extreme ultraviolet ("EUV") laser that is desired to be measured, and  $BW_4$  can be a second such bandwidth parameter of the incident beam that is desired to be measured. According to an embodiment of the present invention then, either  $BW_3$  or  
25        $BW_4$  may be calculated from the outputs  $BW_1$  and  $BW_2$  and precalculated coefficients, as described above, provided that the measurement resulting in  $BW_1$  is predominantly sensitive to  $BW_3$  and only somewhat sensitive to  $BW_4$  and the measurement of  $BW_1$  is predominantly sensitive to  $BW_4$  and only somewhat sensitive to  $BW_3$ .

30       It will also be understood that the "actual" bandwidth cannot be precisely measured. Even perfect calibration constant coefficients according to an

embodiment of the present invention would have at least the error of the measuring LTB spectrometer, which is small, but finite. Applicant estimates such error to be in the femto-meter range. Therefore the term “actual bandwidth” as used in the specification and claims refers to the bandwidth calculated from the parallel inputs  
5 and the precalculated calibration coefficients for each of the two parallel wave meter instruments. This is not “actual” bandwidth, but is much closer than with prior art bandwidth detectors, especially in the ranges discussed above for, e.g., wavelength and bandwidth, where changes, e.g., in the operating E95 and like error producing effects more pronouncedly interfere with the ability to utilize existing wave meters  
10 with the necessary degree of confidence of translation of what is measured to the “actual” bandwidth.

Those skilled in the art will appreciate that the apparatus and methods of the present invention includes mathematical approximations and calibration methods that make the apparatus simple to implement using straightforward algebra, and does  
15 not require detailed knowledge of the spectral shape of the input source or impulse response functions of the spectrometer(s). Those skilled in the art will also appreciate that a feature of the described embodiment of the present invention is that it is relatively computationally simple, involving simple mathematical operations.

The above described embodiments of the present invention are intended only  
20 for explanation and illustration purposes and are not the only embodiments in which the present invention may reside. Those skilled in the art will understand that many modifications and changes may be made to the described embodiments without changing the intent and spirit of the present invention. For example, other bandwidth detection apparatus besides etalons may be utilized to provide the parallel  
25 bandwidth measurements for calibrations and incorporation in the calibration equations for determination of the precomputed calibrations coefficients to be employed later with the actual readings from the two bandwidth detection meters in parallel for measurement of actual FWXM and EX. A wide range of differential bandpass values for the two parallel bandwidth detectors may be utilized and certain  
30 ranges may prove better for different applications, varying requirements for wavelength, bandwidth, etc. In addition, while the present invention has been

explained with an embodiment utilizing two etalon spectrometers and two plane models, it may be possible to implement the invention utilizing, e.g., three or four etalons/spectrometers instead of two, and/or possibly some other kind of modeling different from the plane  $z=ax+by+c$  (, e.g., other relatively simple surfaces, e.g., a

5 parabolic surface, depending on what the spectral variations in the source are expected to be what kind of spectrometers are used use. The scope of the present invention, therefore, should be considered in light only of the appended claims and legal equivalents.

## CLAIMS

I/WE CLAIM:

1. A bandwidth meter for measuring the bandwidth of a spectrum of light emitted from a laser input to the bandwidth meter comprising:

a first optical bandwidth detector providing a first output representative of a parameter which is indicative of the bandwidth of the light emitted from the laser as actually measured by the first bandwidth detector;

a second optical bandwidth detector providing a second output representative of a parameter which is indicative of bandwidth of the light emitted from the laser as actually measured by the second bandwidth detector; and,

an actual bandwidth calculation apparatus adapted to utilize the first output and the second output as part of a multivariable linear equation employing predetermined calibration variables specific to either the first bandwidth detector or the second bandwidth detector, to calculate an actual bandwidth parameter.

2. The apparatus of claim 1 further comprising:

the actual bandwidth parameter is a spectrum full width at some percent of the maximum within the full width of the spectrum of light emitted from the laser ("FWXM").

3. The apparatus of claim 1, further comprising:

the actual bandwidth parameter is a width between two points on the spectrum defining a content of the spectrum containing some percentage of the energy of the full spectrum of the spectrum of light emitted from the laser ("EX").

4. The apparatus of claim 1 further comprising:

the first bandwidth detector is an etalon and the first output is representative of a fringe width of a fringe of an optical output of the etalon at FWXM; and,

the second bandwidth detector is an etalon and the second output is representative of a fringe width of an optical output of the etalon at FWXM.

5. The apparatus of claim 2 further comprising:

the first bandwidth detector is an etalon and the first output representative of a fringe width of a fringe of an optical output of the etalon at FWXM, and,

the second bandwidth detector is an etalon and the second output is a fringe width of an optical output of the etalon at FWXM.

6. The apparatus of claim 3 further comprising:

the first bandwidth detector is an etalon and the first output representative of a fringe width of a fringe of an optical output of the etalon at FWXM; and,

the second bandwidth detector is an etalon and the second output is a fringe width of an optical output of the etalon at FWXM.

7. The apparatus of claim 1, further comprising:

the precomputed calibration variables are derived from a three dimensional plot representing the first output of the first bandwidth detector in relation to a calibrating input light with known values of a first actual bandwidth parameter and of a second actual bandwidth parameter, and from a three dimensional plot representing the second output of the second bandwidth detector in relation to a calibrating input light with known values of a first actual bandwidth parameter and of a second actual bandwidth parameter.

8. The apparatus of claim 2, further comprising:

the precomputed calibration variables are derived from a three dimensional plot representing the first output of the first bandwidth detector in relation to a calibrating input light with known values of a first actual bandwidth parameter and of a second actual bandwidth parameter, and from a three dimensional plot representing the second output of the second bandwidth detector in relation to a calibrating input light with known values of the first actual bandwidth parameter and of the second actual bandwidth parameter.

9. The apparatus of claim 3, further comprising:

the precomputed calibration variables are derived from a three dimensional plot representing the first output of the first bandwidth detector in relation to a calibrating input light with known values of the first actual bandwidth parameter and of the second actual bandwidth parameter, and from a three dimensional plot representing the second output of the second bandwidth detector in relation to a calibrating input light with known values of the first actual bandwidth parameter and of the second actual bandwidth parameter.

10. The apparatus of claim 4, further comprising:

the precomputed calibration variables are derived from a three dimensional plot representing the first output of the first bandwidth detector in relation to a calibrating input light with known values of the first actual bandwidth parameter and of the second actual bandwidth parameter, and from a three dimensional plot representing the second output of the second bandwidth detector in relation to a calibrating input light with known values of the first actual bandwidth parameter and of the second actual bandwidth parameter.

11. The apparatus of claim 5, further comprising:

the precomputed calibration variables are derived from a three dimensional plot representing the first output of the first bandwidth detector in relation to a calibrating input light with known values of the first actual bandwidth parameter and of the second actual bandwidth parameter, and from a three dimensional plot representing the second output of the second bandwidth detector in relation to a calibrating input light with known values of the first actual bandwidth parameter and of the second actual bandwidth parameter.

12. The apparatus of claim 6, further comprising:

the precomputed calibration variables are derived from a three dimensional plot representing the first output of the first bandwidth detector in relation to a calibrating input light with known values of the first actual bandwidth parameter and of the second actual bandwidth parameter, and from a three dimensional plot

representing the second output of the second bandwidth detector in relation to a calibrating input light with known values of the first actual bandwidth parameter and of the second actual bandwidth parameter.

13. The apparatus of claim 7, further comprising:

the first actual bandwidth parameter is a spectrum FWXM of the spectrum of light emitted from the laser; and,

the second actual bandwidth parameter is an EX of the spectrum of light emitted from the laser.

14. The apparatus of claim 8, further comprising:

the first actual bandwidth parameter is a spectrum FWXM of the spectrum of light emitted from the laser; and,

the second actual bandwidth parameter is an EX of the spectrum of light emitted from the laser.

15. The apparatus of claim 9, further comprising:

the first actual bandwidth parameter is a spectrum FWXM of the spectrum of light emitted from the laser; and,

the second actual bandwidth parameter is an EX of the spectrum of light emitted from the laser.

16. The apparatus of claim 10, further comprising:

the first actual bandwidth parameter is a spectrum FWHM of the spectrum of light emitted from the laser; and,

the second actual bandwidth parameter is an EX of the spectrum of light emitted from the laser.

17. The apparatus of claim 11, further comprising:

the first actual bandwidth parameter is a spectrum FWHM of the spectrum of light emitted from the laser; and,

the second actual bandwidth parameter is an EX of the spectrum of light emitted from the laser.

18. The apparatus of claim 12, further comprising:

the first actual bandwidth parameter is a spectrum FWHM of the spectrum of light emitted from the laser; and,

the second actual bandwidth parameter is an EX of the spectrum of light emitted from the laser.

19. The apparatus of claim 13, further comprising:

the first three dimensional plot provides the solution:

$(\text{first output}) = (a * (\text{calibrating input light known value of FWXM})) + (b * (\text{calibrating input light known value of EX}) + c;$  and

the second three dimensional plot provides the solution:

$(\text{second output}) = (a * (\text{calibrating input light known value of FWXM})) + (b * (\text{calibrating input light known value of EX}) + c;$  and

the actual bandwidth calculation apparatus uses the derived equation:

$(\text{first actual bandwidth parameter}) = ((b * (\text{second output})) - (e * (\text{first output})) + ce - bf) / (bd - ae),$

or the equation:

$(\text{second actual bandwidth parameter}) = ((a * (\text{second output})) - (d * (\text{first output})) + cd - af) / (ae - bd).$

20. The apparatus of claim 14, further comprising:

the first three dimensional plot provides the solution:

$(\text{first output}) = (a * (\text{calibrating input light known value of FWXM})) + (b * (\text{calibrating input light known value of EX}) + c;$  and

the second three dimensional plot provides the solution:

$(\text{second output}) = (a * (\text{calibrating input light known value of FWXM})) + (b * (\text{calibrating input light known value of EX}) + c;$  and

the actual bandwidth calculation apparatus uses the derived equation:

(first actual bandwidth parameter) =  $((b * (\text{second output})) - (e * (\text{first output})) + ce - bf) / (bd - ae)$ ,

or the equation:

(second actual bandwidth parameter) =  $((a * (\text{second output})) - (d * (\text{first output})) + cd - af) / (ae - bd)$ .

21. The apparatus of claim 15, further comprising:

the first three dimensional plot provides the solution:

(first output) =  $(a * (\text{calibrating input light known value of FWXM})) + (b * (\text{calibrating input light known value of EX}) + c$ ; and

the second three dimensional plot provides the solution:

(second output) =  $(a * (\text{calibrating input light known value of FWXM})) + (b * (\text{calibrating input light known value of EX}) + c$ ; and

the actual bandwidth calculation apparatus uses the derived equation:

(first actual bandwidth parameter) =  $((b * (\text{second output})) - (e * (\text{first output})) + ce - bf) / (bd - ae)$ ,

or the equation:

(second actual bandwidth parameter) =  $((a * (\text{second output})) - (d * (\text{first output})) + cd - af) / (ae - bd)$ .

22. The apparatus of claim 16, further comprising:

the first three dimensional plot provides the solution:

(first output) =  $(a * (\text{calibrating input light known value of FWXM})) + (b * (\text{calibrating input light known value of EX}) + c$ ; and

the second three dimensional plot provides the solution:

(second output) =  $(a * (\text{calibrating input light known value of FWXM})) + (b * (\text{calibrating input light known value of EX}) + c$ ; and

the actual bandwidth calculation apparatus uses the derived equation:

(first actual bandwidth parameter) =  $((b * (\text{second output})) - (e * (\text{first output})) + ce - bf) / (bd - ae)$ ,

or the equation:

$$(\text{second actual bandwidth parameter}) = ((a * (\text{second output})) - (d * (\text{first output})) + cd - af) / (ae - bd).$$

23. The apparatus of claim 17, further comprising:

the first three dimensional plot provides the solution:

$$(\text{first output}) = (a * (\text{calibrating input light known value of FWXM})) + (b * (\text{calibrating input light known value of EX}) + c; \text{ and}$$

the second three dimensional plot provides the solution:

$$(\text{second output}) = (a * (\text{calibrating input light known value of FWXM})) + (b * (\text{calibrating input light known value of EX}) + c; \text{ and}$$

the actual bandwidth calculation apparatus uses the derived equation:

$$(\text{first actual bandwidth parameter}) = ((b * (\text{second output})) - (e * (\text{first output})) + ce - bf) / (bd - ae),$$

or the equation:

$$(\text{second actual bandwidth parameter}) = ((a * (\text{second output})) - (d * (\text{first output})) + cd - af) / (ae - bd).$$

24. The apparatus of claim 18, further comprising:

the first three dimensional plot provides the solution:

$$(\text{first output}) = (a * (\text{calibrating input light known value of FWXM})) + (b * (\text{calibrating input light known value of EX}) + c; \text{ and}$$

the second three dimensional plot provides the solution:

$$(\text{second output}) = (a * (\text{calibrating input light known value of FWXM})) + (b * (\text{calibrating input light known value of EX}) + c; \text{ and}$$

the actual bandwidth calculation apparatus uses the derived equation:

$$(\text{first actual bandwidth parameter}) = ((b * (\text{second output})) - (e * (\text{first output})) + ce - bf) / (bd - ae),$$

or the equation:

$$(\text{second actual bandwidth parameter}) = ((a * (\text{second output})) - (d * (\text{first output})) + cd - af) / (ae - bd).$$

25. The apparatus of claim 19, further comprising:

the calibrating input light known value of FWXM is FWHM and the first actual bandwidth parameter is FWHM and the calibrating input light known value of EX is E95 and the second actual bandwidth parameter is E95.

26. The apparatus of claim 20, further comprising:

the calibrating input light known value of FWXM is FWHM and the first actual bandwidth parameter is FWHM and the calibrating input light known value of EX is E95 and the second actual bandwidth parameter is E95.

27. The apparatus of claim 21, further comprising:

the calibrating input light known value of FWXM is FWHM and the first actual bandwidth parameter is FWHM and the calibrating input light known value of EX is E95 and the second actual bandwidth parameter is E95.

28. The apparatus of claim 22, further comprising:

the calibrating input light known value of FWXM is FWHM and the first actual bandwidth parameter is FWHM and the calibrating input light known value of EX is E95 and the second actual bandwidth parameter is E95.

29. The apparatus of claim 23, further comprising:

the calibrating input light known value of FWXM is FWHM and the first actual bandwidth parameter is FWHM and the calibrating input light known value of EX is E95 and the second actual bandwidth parameter is E95.

30. The apparatus of claim 24, further comprising:

the calibrating input light known value of FWXM is FWHM and the first actual bandwidth parameter is FWHM and the calibrating input light known value of EX is E95 and the second actual bandwidth parameter is E95.

31. The apparatus of claim 19, further comprising:

the transfer function of the first optical bandwidth detector is selected to be much more sensitive to FWXM than to EX and the transfer function of the second optical bandwidth detector is selected to be much more sensitive to EX than to FWXM.

32. The apparatus of claim 20, further comprising:

the transfer function of the first optical bandwidth detector is selected to be much more sensitive to FWXM than to EX and the transfer function of the second optical bandwidth detector is selected to be much more sensitive to EX than to FWXM.

33. The apparatus of claim 21, further comprising:

the transfer function of the first optical bandwidth detector is selected to be much more sensitive to FWXM than to EX and the transfer function of the second optical bandwidth detector is selected to be much more sensitive to EX than to FWXM.

34. The apparatus of claim 22, further comprising:

the transfer function of the first optical bandwidth detector is selected to be much more sensitive to FWXM than to EX and the transfer function of the second optical bandwidth detector is selected to be much more sensitive to EX than to FWXM.

35. The apparatus of claim 23, further comprising:

the transfer function of the first optical bandwidth detector is selected to be much more sensitive to FWXM than to EX and the transfer function of the second optical bandwidth detector is selected to be much more sensitive to EX than to FWXM.

36. The apparatus of claim 24, further comprising:

the transfer function of the first optical bandwidth detector is selected to be much more sensitive to FWXM than to EX and the transfer function of the second optical bandwidth detector is selected to be much more sensitive to EX than to FWXM.

37. A photolithography light source comprising:

a laser light source; and,

a bandwidth meter for measuring the bandwidth of a spectrum of light emitted from the laser input to the bandwidth meter comprising:

a first wavelength sensitive optical bandwidth detector providing a first output representative of a first parameter which is indicative of the bandwidth of the light emitted from the laser as actually measured by the first bandwidth detector;

a second wavelength sensitive optical bandwidth detector providing a second output representative of the first parameter which is indicative of bandwidth of the light emitted from the laser as actually measured by the second bandwidth detector; and,

an actual bandwidth calculation apparatus adapted to utilize the first output and the second output as part of a multivariable linear equation employing predetermined calibration variables specific to either the first bandwidth detector or the second bandwidth detector, to calculate a first actual bandwidth parameter or a second actual bandwidth parameter for the light emitted from the laser.

38. The apparatus of claim 37 further comprising:

the first actual bandwidth parameter is a spectrum full width at some percent of the maximum within the full width of the spectrum of light emitted from the laser ("FWXM").

39. The apparatus of claim 37, further comprising:

the second actual bandwidth parameter is a width between two points on the spectrum defining a content of the spectrum containing some percentage of the energy of the full spectrum of the spectrum of light emitted from the laser ("EX").

40. The apparatus of claim 37 further comprising:

the first bandwidth detector is an etalon and the first output is representative of a fringe width of a fringe of an optical output of the etalon at FWXM; and,

the second bandwidth detector is an etalon and the second output is representative of a fringe width of an optical output of the etalon at FWXM.

41. The apparatus of claim 38 further comprising:

the first bandwidth detector is an etalon and the first output representative of a fringe width of a fringe of an optical output of the etalon at FWXM, and,

the second bandwidth detector is an etalon and the second output is a fringe width of an optical output of the etalon at FWXM.

42. The apparatus of claim 39 further comprising:

the first bandwidth detector is an etalon and the first output representative of a fringe width of a fringe of an optical output of the etalon at FWXM; and,

the second bandwidth detector is an etalon and the second output is a fringe width of an optical output of the etalon at FWXM.

43. The apparatus of claim 37, further comprising:

the precomputed calibration variables are derived from a three dimensional plot representing the first output of the first bandwidth detector in relation to a calibrating input light with known values of the first actual bandwidth parameter and of the second actual bandwidth parameter, and from a three dimensional plot representing the second output of the second bandwidth detector in relation to a calibrating input light with known values of the first actual bandwidth parameter and of the second actual bandwidth parameter.

44. The apparatus of claim 38, further comprising:

the precomputed calibration variables are derived from a three dimensional plot representing the first output of the first bandwidth detector in relation to a

calibrating input light with known values of the first actual bandwidth parameter and of the second actual bandwidth parameter, and from a three dimensional plot representing the second output of the second bandwidth detector in relation to a calibrating input light with known values of the first actual bandwidth parameter and of the second actual bandwidth parameter.

45. The apparatus of claim 39, further comprising:

the precomputed calibration variables are derived from a three dimensional plot representing the first output of the first bandwidth detector in relation to a calibrating input light with known values of the first actual bandwidth parameter and of the second actual bandwidth parameter, and from a three dimensional plot representing the second output of the second bandwidth detector in relation to a calibrating input light with known values of the first actual bandwidth parameter and of the second actual bandwidth parameter.

46. The apparatus of claim 40, further comprising:

the precomputed calibration variables are derived from a three dimensional plot representing the first output of the first bandwidth detector in relation to a calibrating input light with known values of the first actual bandwidth parameter and of the second actual bandwidth parameter, and from a three dimensional plot representing the second output of the second bandwidth detector in relation to a calibrating input light with known values of the first actual bandwidth parameter and of the second actual bandwidth parameter.

47. The apparatus of claim 41, further comprising:

the precomputed calibration variables are derived from a three dimensional plot representing the first output of the first bandwidth detector in relation to a calibrating input light with known values of the first actual bandwidth parameter and of the second actual bandwidth parameter, and from a three dimensional plot representing the second output of the second bandwidth detector in relation to a

calibrating input light with known values of the first actual bandwidth parameter and of the second actual bandwidth parameter.

48. The apparatus of claim 42, further comprising:

the precomputed calibration variables are derived from a three dimensional plot representing the first output of the first bandwidth detector in relation to a calibrating input light with known values of the first actual bandwidth parameter and of the second actual bandwidth parameter, and from a three dimensional plot representing the second output of the second bandwidth detector in relation to a calibrating input light with known values of the first actual bandwidth parameter and of the second actual bandwidth parameter.

49. The apparatus of claim 43, further comprising:

the first actual bandwidth parameter is a spectrum FWXM of the spectrum of light emitted from the laser; and,

the second actual bandwidth parameter is an EX of the spectrum of light emitted from the laser.

50. The apparatus of claim 44, further comprising:

the first actual bandwidth parameter is a spectrum FWXM of the spectrum of light emitted from the laser; and,

the second actual bandwidth parameter is an EX of the spectrum of light emitted from the laser.

51. The apparatus of claim 45, further comprising:

the first actual bandwidth parameter is a spectrum FWXM of the spectrum of light emitted from the laser; and,

the second actual bandwidth parameter is an EX of the spectrum of light emitted from the laser.

52. The apparatus of claim 46, further comprising:

the first actual bandwidth parameter is a spectrum FWHM of the spectrum of light emitted from the laser; and,

the second actual bandwidth parameter is an EX of the spectrum of light emitted from the laser.

53. The apparatus of claim 47, further comprising:

the first actual bandwidth parameter is a spectrum FWHM of the spectrum of light emitted from the laser; and,

the second actual bandwidth parameter is an EX of the spectrum of light emitted from the laser.

54. The apparatus of claim 48, further comprising:

the first actual bandwidth parameter is a spectrum FWHM of the spectrum of light emitted from the laser; and,

the second actual bandwidth parameter is an EX of the spectrum of light emitted from the laser.

55. The apparatus of claim 49, further comprising:

the first three dimensional plot provides the solution:

$(\text{first output}) = (a * (\text{calibrating input light known value of FWXM})) + (b * (\text{calibrating input light known value of EX}) + c;$  and

the second three dimensional plot provides the solution:

$(\text{second output}) = (a * (\text{calibrating input light known value of FWXM})) + (b * (\text{calibrating input light known value of EX}) + c;$  and

the actual bandwidth calculation apparatus uses the derived equation:

$(\text{first actual bandwidth parameter}) = ((b * (\text{second output})) - (e * (\text{first output})) + ce - bf) / (bd - ae),$

or the equation:

$(\text{second actual bandwidth parameter}) = ((a * (\text{second output})) - (d * (\text{first output})) + cd - af) / (ae - bd).$

56. The apparatus of claim 50, further comprising:

the first three dimensional plot provides the solution:

$(\text{first output}) = (a * (\text{calibrating input light known value of FWXM})) + (b * (\text{calibrating input light known value of EX}) + c;$  and

the second three dimensional plot provides the solution:

$(\text{second output}) = (a * (\text{calibrating input light known value of FWXM})) + (b * (\text{calibrating input light known value of EX}) + c;$  and

the actual bandwidth calculation apparatus uses the derived equation:

$(\text{first actual bandwidth parameter}) = ((b * (\text{second output})) - (e * (\text{first output})) + ce - bf) / (bd - ae),$

or the equation:

$(\text{second actual bandwidth parameter}) = ((a * (\text{second output})) - (d * (\text{first output})) + cd - af) / (ae - bd).$

57. The apparatus of claim 51, further comprising:

the first three dimensional plot provides the solution:

$(\text{first output}) = (a * (\text{calibrating input light known value of FWXM})) + (b * (\text{calibrating input light known value of EX}) + c;$  and

the second three dimensional plot provides the solution:

$(\text{second output}) = (a * (\text{calibrating input light known value of FWXM})) + (b * (\text{calibrating input light known value of EX}) + c;$  and

the actual bandwidth calculation apparatus uses the derived equation:

$(\text{first actual bandwidth parameter}) = ((b * (\text{second output})) - (e * (\text{first output})) + ce - bf) / (bd - ae),$

or the equation:

$(\text{second actual bandwidth parameter}) = ((a * (\text{second output})) - (d * (\text{first output})) + cd - af) / (ae - bd).$

58. The apparatus of claim 52, further comprising:

the first three dimensional plot provides the solution:

(first output) = (a \* (calibrating input light known value of FWXM)) + (b \* (calibrating input light known value of EX) + c; and

the second three dimensional plot provides the solution:

(second output) = (a \* (calibrating input light known value of FWXM)) + (b \* (calibrating input light known value of EX) + c; and

the actual bandwidth calculation apparatus uses the derived equation:

(first actual bandwidth parameter) = ((b \* (second output)) - (e \* (first output)) + ce - bf) / (bd - ae),

or the equation:

(second actual bandwidth parameter) = ((a \* (second output)) - (d \* (first output)) + cd - af) / (ae - bd).

59. The apparatus of claim 53, further comprising:

the first three dimensional plot provides the solution:

(first output) = (a \* (calibrating input light known value of FWXM)) + (b \* (calibrating input light known value of EX) + c; and

the second three dimensional plot provides the solution:

(second output) = (a \* (calibrating input light known value of FWXM)) + (b \* (calibrating input light known value of EX) + c; and

the actual bandwidth calculation apparatus uses the derived equation:

(first actual bandwidth parameter) = ((b \* (second output)) - (e \* (first output)) + ce - bf) / (bd - ae),

or the equation:

(second actual bandwidth parameter) = ((a \* (second output)) - (d \* (first output)) + cd - af) / (ae - bd).

60. The apparatus of claim 54, further comprising:

the first three dimensional plot provides the solution:

(first output) = (a \* (calibrating input light known value of FWXM)) + (b \* (calibrating input light known value of EX) + c; and

the second three dimensional plot provides the solution:

$(\text{second output}) = (a * (\text{calibrating input light known value of FWXM})) + (b * (\text{calibrating input light known value of EX}) + c;$  and

the actual bandwidth calculation apparatus uses the derived equation:

$(\text{first actual bandwidth parameter}) = ((b * (\text{second output})) - (e * (\text{first output})) + ce - bf) / (bd - ae),$

or the equation:

$(\text{second actual bandwidth parameter}) = ((a * (\text{second output})) - (d * (\text{first output})) + cd - af) / (ae - bd).$

61. The apparatus of claim 55, further comprising:

the calibrating input light known value of FWXM is FWHM and the first actual bandwidth parameter is FWHM and the calibrating input light known value of EX is E95 and the second actual bandwidth parameter is E95.

62. The apparatus of claim 56, further comprising:

the calibrating input light known value of FWXM is FWHM and the first actual bandwidth parameter is FWHM and the calibrating input light known value of EX is E95 and the second actual bandwidth parameter is E95.

63. The apparatus of claim 57, further comprising:

the calibrating input light known value of FWXM is FWHM and the first actual bandwidth parameter is FWHM and the calibrating input light known value of EX is E95 and the second actual bandwidth parameter is E95.

64. The apparatus of claim 58, further comprising:

the calibrating input light known value of FWXM is FWHM and the first actual bandwidth parameter is FWHM and the calibrating input light known value of EX is E95 and the second actual bandwidth parameter is E95.

65. The apparatus of claim 59, further comprising:

the calibrating input light known value of FWXM is FWHM and the first actual bandwidth parameter is FWHM and the calibrating input light known value of EX is E95 and the second actual bandwidth parameter is E95.

66. The apparatus of claim 60, further comprising:

the calibrating input light known value of FWXM is FWHM and the first actual bandwidth parameter is FWHM and the calibrating input light known value of EX is E95 and the second actual bandwidth parameter is E95.

67. The apparatus of claim 55, further comprising:

the transfer function of the first optical bandwidth detector is selected to be much more sensitive to FWXM than to EX and the transfer function of the second optical bandwidth detector is selected to be much more sensitive to EX than to FWXM.

68. The apparatus of claim 56, further comprising:

the transfer function of the first optical bandwidth detector is selected to be much more sensitive to FWXM than to EX and the transfer function of the second optical bandwidth detector is selected to be much more sensitive to EX than to FWXM.

69. The apparatus of claim 57, further comprising:

the transfer function of the first optical bandwidth detector is selected to be much more sensitive to FWXM than to EX and the transfer function of the second optical bandwidth detector is selected to be much more sensitive to EX than to FWXM.

70. The apparatus of claim 58, further comprising:

the transfer function of the first optical bandwidth detector is selected to be much more sensitive to FWXM than to EX and the transfer function of the second

optical bandwidth detector is selected to be much more sensitive to EX than to FWXM.

71. The apparatus of claim 59, further comprising:

the transfer function of the first optical bandwidth detector is selected to be much more sensitive to FWXM than to EX and the transfer function of the second optical bandwidth detector is selected to be much more sensitive to EX than to FWXM.

72. The apparatus of claim 60, further comprising:

the transfer function of the first optical bandwidth detector is selected to be much more sensitive to FWXM than to EX and the transfer function of the second optical bandwidth detector is selected to be much more sensitive to EX than to FWXM.

73. A photolithography tool comprising:

a photolithography light source comprising:

a bandwidth meter for measuring the bandwidth of a spectrum of light emitted from a laser input to the bandwidth meter comprising:

a first wavelength sensitive optical bandwidth detector providing a first output representative of a first parameter which is indicative of the bandwidth of the light emitted from the laser as actually measured by the first bandwidth detector;

a second wavelength sensitive optical bandwidth detector providing a second output representative of the first parameter which is indicative of bandwidth of the light emitted from the laser as actually measured by the second bandwidth detector; and,

an actual bandwidth calculation apparatus adapted to utilize the first output and the second output as part of a multivariable linear equation employing predetermined calibration variables specific to either the first bandwidth detector or the second bandwidth detector, to calculate a first actual bandwidth parameter or a second actual bandwidth parameter for the light emitted from the laser.

74. The apparatus of claim 73 further comprising:

the first actual bandwidth parameter is a spectrum full width at some percent of the maximum within the full width of the spectrum of light emitted from the laser ("FWXM").

75. The apparatus of claim 73, further comprising:

the second actual bandwidth parameter is a width between two points on the spectrum defining a content of the spectrum containing some percentage of the energy of the full spectrum of the spectrum of light emitted from the laser ("EX").

76. The apparatus of claim 73 further comprising:

the first bandwidth detector is an etalon and the first output is representative of a fringe width of a fringe of an optical output of the etalon at FWXM; and,

the second bandwidth detector is an etalon and the second output is representative of a fringe width of an optical output of the etalon at FWXM.

77. The apparatus of claim 74 further comprising:

the first bandwidth detector is an etalon and the first output representative of a fringe width of a fringe of an optical output of the etalon at FWXM, and,

the second bandwidth detector is an etalon and the second output is a fringe width of an optical output of the etalon at FWXM.

78. The apparatus of claim 75 further comprising:

the first bandwidth detector is an etalon and the first output representative of a fringe width of a fringe of an optical output of the etalon at FWXM; and,

the second bandwidth detector is an etalon and the second output is a fringe width of an optical output of the etalon at FWXM.

79. The apparatus of claim 73, further comprising:

the precomputed calibration variables are derived from a three dimensional plot representing the first output of the first bandwidth detector in relation to a calibrating input light with known values of the first actual bandwidth parameter and of the second actual bandwidth parameter, and from a three dimensional plot representing the second output of the second bandwidth detector in relation to a calibrating input light with known values of the first actual bandwidth parameter and of the second actual bandwidth parameter.

80. The apparatus of claim 74, further comprising:

the precomputed calibration variables are derived from a three dimensional plot representing the first output of the first bandwidth detector in relation to a calibrating input light with known values of the first actual bandwidth parameter and of the second actual bandwidth parameter, and from a three dimensional plot representing the second output of the second bandwidth detector in relation to a calibrating input light with known values of the first actual bandwidth parameter and of the second actual bandwidth parameter.

81. The apparatus of claim 75, further comprising:

the precomputed calibration variables are derived from a three dimensional plot representing the first output of the first bandwidth detector in relation to a calibrating input light with known values of the first actual bandwidth parameter and of the second actual bandwidth parameter, and from a three dimensional plot representing the second output of the second bandwidth detector in relation to a calibrating input light with known values of the first actual bandwidth parameter and of the second actual bandwidth parameter.

82. The apparatus of claim 76, further comprising:

the precomputed calibration variables are derived from a three dimensional plot representing the first output of the first bandwidth detector in relation to a calibrating input light with known values of the first actual bandwidth parameter and of the second actual bandwidth parameter, and from a three dimensional plot

representing the second output of the second bandwidth detector in relation to a calibrating input light with known values of the first actual bandwidth parameter and of the second actual bandwidth parameter.

83. The apparatus of claim 77, further comprising:

the precomputed calibration variables are derived from a three dimensional plot representing the first output of the first bandwidth detector in relation to a calibrating input light with known values of the first actual bandwidth parameter and of the second actual bandwidth parameter, and from a three dimensional plot representing the second output of the second bandwidth detector in relation to a calibrating input light with known values of the first actual bandwidth parameter and of the second actual bandwidth parameter.

84. The apparatus of claim 78, further comprising:

the precomputed calibration variables are derived from a three dimensional plot representing the first output of the first bandwidth detector in relation to a calibrating input light with known values of the first actual bandwidth parameter and of the second actual bandwidth parameter, and from a three dimensional plot representing the second output of the second bandwidth detector in relation to a calibrating input light with known values of the first actual bandwidth parameter and of the second actual bandwidth parameter.

85. The apparatus of claim 79, further comprising:

the first actual bandwidth parameter is a spectrum FWXM of the spectrum of light emitted from the laser; and,

the second actual bandwidth parameter is an EX of the spectrum of light emitted from the laser.

86. The apparatus of claim 80, further comprising:

the first actual bandwidth parameter is a spectrum FWXM of the spectrum of light emitted from the laser; and,

the second actual bandwidth parameter is an EX of the spectrum of light emitted from the laser.

87. The apparatus of claim 81, further comprising:

the first actual bandwidth parameter is a spectrum FWXM of the spectrum of light emitted from the laser; and,

the second actual bandwidth parameter is an EX of the spectrum of light emitted from the laser.

88. The apparatus of claim 82, further comprising:

the first actual bandwidth parameter is a spectrum FWHM of the spectrum of light emitted from the laser; and,

the second actual bandwidth parameter is an EX of the spectrum of light emitted from the laser.

89. The apparatus of claim 83, further comprising:

the first actual bandwidth parameter is a spectrum FWHM of the spectrum of light emitted from the laser; and,

the second actual bandwidth parameter is an EX of the spectrum of light emitted from the laser.

90. The apparatus of claim 84, further comprising:

the first actual bandwidth parameter is a spectrum FWHM of the spectrum of light emitted from the laser; and,

the second actual bandwidth parameter is an EX of the spectrum of light emitted from the laser.

91. The apparatus of claim 85, further comprising:

the first three dimensional plot provides the solution:

$(\text{first output}) = (a * (\text{calibrating input light known value of FWXM})) + (b * (\text{calibrating input light known value of EX}) + c;$  and

the second three dimensional plot provides the solution:

$(\text{second output}) = (a * (\text{calibrating input light known value of FWXM})) + (b * (\text{calibrating input light known value of EX}) + c;$  and

the actual bandwidth calculation apparatus uses the derived equation:

$(\text{first actual bandwidth parameter}) = ((b * (\text{second output})) - (e * (\text{first output})) + ce - bf) / (bd - ae),$

or the equation:

$(\text{second actual bandwidth parameter}) = ((a * (\text{second output})) - (d * (\text{first output})) + cd - af) / (ae - bd).$

92. The apparatus of claim 86, further comprising:

the first three dimensional plot provides the solution:

$(\text{first output}) = (a * (\text{calibrating input light known value of FWXM})) + (b * (\text{calibrating input light known value of EX}) + c;$  and

the second three dimensional plot provides the solution:

$(\text{second output}) = (a * (\text{calibrating input light known value of FWXM})) + (b * (\text{calibrating input light known value of EX}) + c;$  and

the actual bandwidth calculation apparatus uses the derived equation:

$(\text{first actual bandwidth parameter}) = ((b * (\text{second output})) - (e * (\text{first output})) + ce - bf) / (bd - ae),$

or the equation:

$(\text{second actual bandwidth parameter}) = ((a * (\text{second output})) - (d * (\text{first output})) + cd - af) / (ae - bd).$

93. The apparatus of claim 87, further comprising:

the first three dimensional plot provides the solution:

$(\text{first output}) = (a * (\text{calibrating input light known value of FWXM})) + (b * (\text{calibrating input light known value of EX}) + c;$  and

the second three dimensional plot provides the solution:

$(\text{second output}) = (a * (\text{calibrating input light known value of FWXM})) + (b * (\text{calibrating input light known value of EX}) + c;$  and

the actual bandwidth calculation apparatus uses the derived equation:

$$(\text{first actual bandwidth parameter}) = ((b * (\text{second output})) - (e * (\text{first output})) + ce - bf) / (bd - ae),$$

or the equation:

$$(\text{second actual bandwidth parameter}) = ((a * (\text{second output})) - (d * (\text{first output})) + cd - af) / (ae - bd).$$

94. The apparatus of claim 88, further comprising:

the first three dimensional plot provides the solution:

$$(\text{first output}) = (a * (\text{calibrating input light known value of FWXM})) + (b * (\text{calibrating input light known value of EX}) + c; \text{ and}$$

the second three dimensional plot provides the solution:

$$(\text{second output}) = (a * (\text{calibrating input light known value of FWXM})) + (b * (\text{calibrating input light known value of EX}) + c; \text{ and}$$

the actual bandwidth calculation apparatus uses the derived equation:

$$(\text{first actual bandwidth parameter}) = ((b * (\text{second output})) - (e * (\text{first output})) + ce - bf) / (bd - ae),$$

or the equation:

$$(\text{second actual bandwidth parameter}) = ((a * (\text{second output})) - (d * (\text{first output})) + cd - af) / (ae - bd).$$

95. The apparatus of claim 89, further comprising:

the first three dimensional plot provides the solution:

$$(\text{first output}) = (a * (\text{calibrating input light known value of FWXM})) + (b * (\text{calibrating input light known value of EX}) + c; \text{ and}$$

the second three dimensional plot provides the solution:

$$(\text{second output}) = (a * (\text{calibrating input light known value of FWXM})) + (b * (\text{calibrating input light known value of EX}) + c; \text{ and}$$

the actual bandwidth calculation apparatus uses the derived equation:

$$(\text{first actual bandwidth parameter}) = ((b * (\text{second output})) - (e * (\text{first output})) + ce - bf) / (bd - ae),$$

or the equation:

$$(\text{second actual bandwidth parameter}) = ((a * (\text{second output})) - (d * (\text{first output})) + cd - af) / (ae - bd).$$

96. The apparatus of claim 90, further comprising:

the first three dimensional plot provides the solution:

$$(\text{first output}) = (a * (\text{calibrating input light known value of FWXM})) + (b * (\text{calibrating input light known value of EX}) + c; \text{ and}$$

the second three dimensional plot provides the solution:

$$(\text{second output}) = (a * (\text{calibrating input light known value of FWXM})) + (b * (\text{calibrating input light known value of EX}) + c; \text{ and}$$

the actual bandwidth calculation apparatus uses the derived equation:

$$(\text{first actual bandwidth parameter}) = ((b * (\text{second output})) - (e * (\text{first output})) + ce - bf) / (bd - ae),$$

or the equation:

$$(\text{second actual bandwidth parameter}) = ((a * (\text{second output})) - (d * (\text{first output})) + cd - af) / (ae - bd).$$

97. The apparatus of claim 91, further comprising:

the calibrating input light known value of FWXM is FWHM and the first actual bandwidth parameter is FWHM and the calibrating input light known value of EX is E95 and the second actual bandwidth parameter is E95.

98. The apparatus of claim 92, further comprising:

the calibrating input light known value of FWXM is FWHM and the first actual bandwidth parameter is FWHM and the calibrating input light known value of EX is E95 and the second actual bandwidth parameter is E95.

99. The apparatus of claim 93, further comprising:

the calibrating input light known value of FWXM is FWHM and the first actual bandwidth parameter is FWHM and the calibrating input light known value of EX is E95 and the second actual bandwidth parameter is E95.

100. The apparatus of claim 94, further comprising:

the calibrating input light known value of FWXM is FWHM and the first actual bandwidth parameter is FWHM and the calibrating input light known value of EX is E95 and the second actual bandwidth parameter is E95.

101. The apparatus of claim 95, further comprising:

the calibrating input light known value of FWXM is FWHM and the first actual bandwidth parameter is FWHM and the calibrating input light known value of EX is E95 and the second actual bandwidth parameter is E95.

102. The apparatus of claim 96, further comprising:

the calibrating input light known value of FWXM is FWHM and the first actual bandwidth parameter is FWHM and the calibrating input light known value of EX is E95 and the second actual bandwidth parameter is E95.

103. The apparatus of claim 97, further comprising:

the transfer function of the first optical bandwidth detector is selected to be much more sensitive to FWXM than to EX and the transfer function of the second optical bandwidth detector is selected to be much more sensitive to EX than to FWXM.

104. The apparatus of claim 98, further comprising:

the transfer function of the first optical bandwidth detector is selected to be much more sensitive to FWXM than to EX and the transfer function of the second optical bandwidth detector is selected to be much more sensitive to EX than to FWXM.

105. The apparatus of claim 99, further comprising:

the transfer function of the first optical bandwidth detector is selected to be much more sensitive to FWXM than to EX and the transfer function of the second optical bandwidth detector is selected to be much more sensitive to EX than to FWXM.

106. The apparatus of claim 100, further comprising:

the transfer function of the first optical bandwidth detector is selected to be much more sensitive to FWXM than to EX and the transfer function of the second optical bandwidth detector is selected to be much more sensitive to EX than to FWXM.

107. The apparatus of claim 101, further comprising:

the transfer function of the first optical bandwidth detector is selected to be much more sensitive to FWXM than to EX and the transfer function of the second optical bandwidth detector is selected to be much more sensitive to EX than to FWXM.

108. The apparatus of claim 102, further comprising:

the transfer function of the first optical bandwidth detector is selected to be much more sensitive to FWXM than to EX and the transfer function of the second optical bandwidth detector is selected to be much more sensitive to EX than to FWXM.

109. A bandwidth measuring means for measuring the bandwidth of a spectrum of light emitted from a laser input to the bandwidth measuring means comprising:

a first wavelength sensitive optical bandwidth detector means for providing a first output representative of a first parameter which is indicative of the bandwidth of the light emitted from the laser as actually measured by the first bandwidth detector means;

a second wavelength sensitive optical bandwidth detector means for providing a second output representative of a first parameter which is indicative of bandwidth of the light emitted from the laser as actually measured by the second bandwidth detector means; and,

an actual bandwidth calculation means for, utilizing the first output and the second output as part of a multivariable linear equation employing precomputed calibration variables specific to either the first bandwidth detector means or the second bandwidth detector means, calculating a first actual bandwidth parameter or a second actual bandwidth parameter for the light emitted from the laser.

110. The apparatus of claim 109 further comprising:

the first actual bandwidth parameter is a FWXM of the spectrum of light emitted from the laser.

111. The apparatus of claim 109, further comprising:

the second actual bandwidth parameter is an EX the spectrum of light emitted from the laser.

112. The apparatus of claim 109 further comprising:

the first bandwidth detector means is an etalon and the first output is representative of a fringe width of a fringe of an optical output of the etalon at some percent of the maximum within the full width of the first output; and,

the second bandwidth detector means is an etalon and the second output is representative of a fringe width of an optical output of the etalon at some percent of the maximum within the full width of the second output.

113. The apparatus of claim 110 further comprising:

the first bandwidth detector means is an etalon and the first output representative of a fringe width of a fringe of an optical output of the etalon at some percent of the maximum within the full width of the first output; and,

the second bandwidth detector means is an etalon and the second output is a fringe width of an optical output of the etalon at some percent of the maximum within the full width of the second output.

114. The apparatus of claim 111 further comprising:

the first bandwidth detector means is an etalon and the first output representative of a fringe width of an optical output of the etalon at some percent of the maximum within the full width of the first output; and,

the second bandwidth detector means is an etalon and the second output is a fringe width of an optical output of the etalon at some percent of the maximum within the full width of the second output.

115. The apparatus of claim 109, further comprising:

the precomputed calibration variables are derived from a three dimensional plot representing the first output of the first bandwidth detector means in relation to a calibrating input light with known values of the first actual bandwidth parameter and of the second actual bandwidth parameter, and from a three dimensional plot representing the second output of the second bandwidth detector means in relation to a calibrating input light with known values of the first actual bandwidth parameter and of the second actual bandwidth parameter.

116. The apparatus of claim 110, further comprising:

the precomputed calibration variables are derived from a three dimensional plot representing the first output of the first bandwidth detector means in relation to a calibrating input light with known values of the first actual bandwidth parameter and of the second actual bandwidth parameter, and from a three dimensional plot representing the second output of the second bandwidth detector means in relation to a calibrating input light with known values of the first actual bandwidth parameter and of the second actual bandwidth parameter.

117. The apparatus of claim 111, further comprising:

the precomputed calibration variables are derived from a three dimensional plot representing the first output of the first bandwidth detector means in relation to a calibrating input light with known values of the first actual bandwidth parameter and of the second actual bandwidth parameter, and from a three dimensional plot representing the second output of the second bandwidth detector means in relation to a calibrating input light with known values of the first actual bandwidth parameter and of the second actual bandwidth parameter.

118. The apparatus of claim 112, further comprising:

the precomputed calibration variables are derived from a three dimensional plot representing the first output of the first bandwidth detector means in relation to a calibrating input light with known values of the first actual bandwidth parameter and of the second actual bandwidth parameter, and from a three dimensional plot representing the second output of the second bandwidth detector means in relation to a calibrating input light with known values of the first actual bandwidth parameter and of the second actual bandwidth parameter.

119. The apparatus of claim 113, further comprising:

the precomputed calibration variables are derived from a three dimensional plot representing the first output of the first bandwidth detector means in relation to a calibrating input light with known values of the first actual bandwidth parameter and of the second actual bandwidth parameter, and from a three dimensional plot representing the second output of the second bandwidth detector means in relation to a calibrating input light with known values of the first actual bandwidth parameter and of the second actual bandwidth parameter.

120. The apparatus of claim 114, further comprising:

the precomputed calibration variables are derived from a three dimensional plot representing the first output of the first bandwidth detector means in relation to a calibrating input light with known values of the first actual bandwidth parameter and of the second actual bandwidth parameter, and from a three dimensional plot

representing the second output of the second bandwidth detector means in relation to a calibrating input light with known values of the first actual bandwidth parameter and of the second actual bandwidth parameter.

121. The apparatus of claim 115, further comprising:

the first actual bandwidth parameter is an FWXM of the spectrum of light emitted from the laser; and,

the second actual bandwidth parameter is an EX of the spectrum of light emitted from the laser.

122. The apparatus of claim 116, further comprising:

the first actual bandwidth parameter is an FWXM of the spectrum of light emitted from the laser; and,

the second actual bandwidth parameter is an EX of the spectrum of light emitted from the laser.

123. The apparatus of claim 117, further comprising:

the first actual bandwidth parameter is an FWXM of the spectrum of light emitted from the laser; and,

the second actual bandwidth parameter is an EX of the spectrum of light emitted from the laser.

124. The apparatus of claim 118, further comprising:

the first actual bandwidth parameter is an FWXM of the spectrum of light emitted from the laser; and,

the second actual bandwidth parameter is an EX of the spectrum of light emitted from the laser.

125. The apparatus of claim 119, further comprising:

the first actual bandwidth parameter is an FWXM of the spectrum of light emitted from the laser; and,

the second actual bandwidth parameter is an EX of the spectrum of light emitted from the laser.

126. The apparatus of claim 120, further comprising:

the first actual bandwidth parameter is an FWXM of the spectrum of light emitted from the laser; and,

the second actual bandwidth parameter is an EX of the spectrum of light emitted from the laser.

127. The apparatus of claim 121, further comprising:

the first three dimensional plot provides the solution:

$(\text{first output}) = (a * (\text{calibrating input light known value of FWXM of the spectrum})) + (b * (\text{calibrating input light known value of EX of the spectrum})) + c;$   
and

the second three dimensional plot provides the solution:

$(\text{second output}) = (a * (\text{calibrating input light known value of FWXM of the spectrum})) + (b * (\text{calibrating input light known value of EX of the spectrum})) + c;$   
and

the actual bandwidth calculation apparatus uses the derived equation:

$(\text{first actual bandwidth parameter}) = ((b * (\text{second output})) - (e * (\text{first output})) + ce - bf) / (bd - ae),$

or the equation:

$(\text{second actual bandwidth parameter}) = ((a * (\text{second output})) - (d * (\text{first output})) + cd - af) / (ae - bd).$

128. The apparatus of claim 122, further comprising:

the first three dimensional plot provides the solution:

$(\text{first output}) = (a * (\text{calibrating input light known value of FWXM of the spectrum})) + (b * (\text{calibrating input light known value of EX of the spectrum})) + c;$   
and

the second three dimensional plot provides the solution:

(second output) = (a \* (calibrating input light known value of FWXM of the spectrum)) + (b \* (calibrating input light known value of EX of the spectrum) + c;  
and

the actual bandwidth calculation apparatus uses the derived equation:

(first actual bandwidth parameter) = ((b \* (second output)) - (e \* (first output)) + ce - bf) / (bd - ae),

or the equation:

(second actual bandwidth parameter) = ((a \* (second output)) - (d \* (first output)) + cd - af) / (ae - bd).

129. The apparatus of claim 123, further comprising:

the first three dimensional plot provides the solution:

(first output) = (a \* (calibrating input light known value of FWXM of the spectrum)) + (b \* (calibrating input light known value of EX of the spectrum) + c;  
and

the second three dimensional plot provides the solution:

(second output) = (a \* (calibrating input light known value of FWXM of the spectrum)) + (b \* (calibrating input light known value of EX of the spectrum) + c;  
and

the actual bandwidth calculation apparatus uses the derived equation:

(first actual bandwidth parameter) = ((b \* (second output)) - (e \* (first output)) + ce - bf) / (bd - ae),

or the equation:

(second actual bandwidth parameter) = ((a \* (second output)) - (d \* (first output)) + cd - af) / (ae - bd).

130. The apparatus of claim 124, further comprising:

the first three dimensional plot provides the solution:

(first output) = (a \* (calibrating input light known value of FWXM of the spectrum)) + (b \* (calibrating input light known value of EX of the spectrum) + c;  
and

the second three dimensional plot provides the solution:

$(\text{second output}) = (a * (\text{calibrating input light known value of FWXM of the spectrum})) + (b * (\text{calibrating input light known value of EX of the spectrum})) + c;$   
and

the actual bandwidth calculation apparatus uses the derived equation:

$(\text{first actual bandwidth parameter}) = ((b * (\text{second output})) - (e * (\text{first output})) + ce - bf) / (bd - ae),$

or the equation:

$(\text{second actual bandwidth parameter}) = ((a * (\text{second output})) - (d * (\text{first output})) + cd - af) / (ae - bd).$

131. The apparatus of claim 125, further comprising:

the first three dimensional plot provides the solution:

$(\text{first output}) = (a * (\text{calibrating input light known value of FWXM of the spectrum})) + (b * (\text{calibrating input light known value of EX of the spectrum})) + c;$   
and

the second three dimensional plot provides the solution:

$(\text{second output}) = (a * (\text{calibrating input light known value of FWXM of the spectrum})) + (b * (\text{calibrating input light known value of EX of the spectrum})) + c;$   
and

the actual bandwidth calculation apparatus uses the derived equation:

$(\text{first actual bandwidth parameter}) = ((b * (\text{second output})) - (e * (\text{first output})) + ce - bf) / (bd - ae),$

or the equation:

$(\text{second actual bandwidth parameter}) = ((a * (\text{second output})) - (d * (\text{first output})) + cd - af) / (ae - bd).$

132. The apparatus of claim 126, further comprising:

the first three dimensional plot provides the solution:

(first output) = (a \* (calibrating input light known value of FWXM of the spectrum)) + (b \* (calibrating input light known value of EX of the spectrum) + c;  
and

the second three dimensional plot provides the solution:

(second output) = (a \* (calibrating input light known value of FWXM of the spectrum)) + (b \* (calibrating input light known value of EX of the spectrum) + c;  
and

the actual bandwidth calculation apparatus uses the derived equation:

(first actual bandwidth parameter) = ((b \* (second output)) - (e \* (first output)) + ce - bf) / (bd - ae),

or the equation:

(second actual bandwidth parameter) = ((a \* (second output)) - (d \* (first output)) + cd - af) / (ae - bd).

133. The apparatus of claim 127, further comprising:

the calibrating input light known value of FWXM is FWHM and the first actual bandwidth parameter is FWHM and the calibrating input light known value of EX is E95 and the second actual bandwidth parameter is E95.

134. The apparatus of claim 128, further comprising:

the calibrating input light known value of FWXM is FWHM and the first actual bandwidth parameter is FWHM and the calibrating input light known value of EX is E95 and the second actual bandwidth parameter is E95.

135. The apparatus of claim 129, further comprising:

the calibrating input light known value of FWXM is FWHM and the first actual bandwidth parameter is FWHM and the calibrating input light known value of EX is E95 and the second actual bandwidth parameter is E95.

136. The apparatus of claim 130, further comprising:

the calibrating input light known value of FWXM is FWHM and the first actual bandwidth parameter is FWHM and the calibrating input light known value of EX is E95 and the second actual bandwidth parameter is E95.

137. The apparatus of claim 131, further comprising:

the calibrating input light known value of FWXM is FWHM and the first actual bandwidth parameter is FWHM and the calibrating input light known value of EX is E95 and the second actual bandwidth parameter is E95.

138. The apparatus of claim 132, further comprising:

the calibrating input light known value of FWXM is FWHM and the first actual bandwidth parameter is FWHM and the calibrating input light known value of EX is E95 and the second actual bandwidth parameter is E95.

139. The apparatus of claim 133, further comprising:

the transfer function of the first optical bandwidth detector is selected to be much more sensitive to the full width at some percent of maximum than to the content of the spectrum containing some percentage of the energy of the full spectrum and the transfer function of the second optical bandwidth detector is selected to be much more sensitive to the content of the spectrum containing some percentage of the energy of the full spectrum than to the full width at some percent of maximum.

140. The apparatus of claim 134, further comprising:

the transfer function of the first optical bandwidth detector is selected to be much more sensitive to the full width at some percent of maximum than to the content of the spectrum containing some percentage of the energy of the full spectrum and the transfer function of the second optical bandwidth detector is selected to be much more sensitive to the content of the spectrum containing some percentage of the energy of the full spectrum than to the full width at some percent of maximum.

141. The apparatus of claim 135, further comprising:

the transfer function of the first optical bandwidth detector is selected to be much more sensitive to the full width at some percent of maximum than to the content of the spectrum containing some percentage of the energy of the full spectrum and the transfer function of the second optical bandwidth detector is selected to be much more sensitive to the content of the spectrum containing some percentage of the energy of the full spectrum than to the full width at some percent of maximum.

142. The apparatus of claim 136, further comprising:

the transfer function of the first optical bandwidth detector is selected to be much more sensitive to the full width at some percent of maximum than to the content of the spectrum containing some percentage of the energy of the full spectrum and the transfer function of the second optical bandwidth detector is selected to be much more sensitive to the content of the spectrum containing some percentage of the energy of the full spectrum than to the full width at some percent of maximum.

143. The apparatus of claim 137, further comprising:

the transfer function of the first optical bandwidth detector is selected to be much more sensitive to the full width at some percent of maximum than to the content of the spectrum containing some percentage of the energy of the full spectrum and the transfer function of the second optical bandwidth detector is selected to be much more sensitive to the content of the spectrum containing some percentage of the energy of the full spectrum than to the full width at some percent of maximum.

144. The apparatus of claim 138, further comprising:

the transfer function of the first optical bandwidth detector is selected to be much more sensitive to the full width at some percent of maximum than to the

content of the spectrum containing some percentage of the energy of the full spectrum and the transfer function of the second optical bandwidth detector is selected to be much more sensitive to the content of the spectrum containing some percentage of the energy of the full spectrum than to the full width at some percent of maximum.

145. A bandwidth measuring method for measuring the bandwidth of a spectrum of light emitted from a laser comprising:

utilizing a first wavelength sensitive optical bandwidth detector to provide a first output representative of a first parameter which is indicative of the bandwidth of the light emitted from the laser as actually measured by the first bandwidth detector;

utilizing a second wavelength sensitive optical bandwidth detector to provide a second output representative of a first parameter which is indicative of bandwidth of the light emitted from the laser as actually measured by the second bandwidth detector; and,

utilizing an actual bandwidth calculation device, utilizing the first output and the second output as part of a multivariable linear equation employing precomputed calibration variables specific to either the first bandwidth detector or the second bandwidth detector, to calculate a first actual bandwidth parameter or a second actual bandwidth parameter for the light emitted from the laser.

146. The method of claim 145 further comprising:

the first actual bandwidth parameter is a FWXM of the spectrum of light emitted from the laser.

147. The method of claim 145, further comprising:

the second actual bandwidth parameter is an EX the spectrum of light emitted from the laser.

148. The method of claim 145 further comprising:

the first bandwidth detector means is an etalon and the first output is representative of a fringe width of a fringe of an optical output of the etalon at some percent of the maximum within the full width of the first output; and,

the second bandwidth detector means is an etalon and the second output is representative of a fringe width of an optical output of the etalon at some percent of the maximum within the full width of the second output.

149. The method of claim 146 further comprising:

the first bandwidth detector means is an etalon and the first output representative of a fringe width of a fringe of an optical output of the etalon at some percent of the maximum within the full width of the first output; and,

the second bandwidth detector means is an etalon and the second output is a fringe width of an optical output of the etalon at some percent of the maximum within the full width of the second output.

150. The method of claim 147 further comprising:

the first bandwidth detector means is an etalon and the first output representative of a fringe width of a fringe of an optical output of the etalon at some percent of the maximum within the full width of the first output; and,

the second bandwidth detector means is an etalon and the second output is a fringe width of an optical output of the etalon at some percent of the maximum within the full width of the second output.

151. The method of claim 145, further comprising:

deriving the precomputed calibration variables from a three dimensional plot representing the first output of the first bandwidth detector means in relation to a calibrating input light with known values of the first actual bandwidth parameter and of the second actual bandwidth parameter, and from a three dimensional plot representing the second output of the second bandwidth detector means in relation to a calibrating input light with known values of the first actual bandwidth parameter and of the second actual bandwidth parameter.

152. The method of claim 146, further comprising:

deriving the precomputed calibration variables from a three dimensional plot representing the first output of the first bandwidth detector means in relation to a calibrating input light with known values of the first actual bandwidth parameter and of the second actual bandwidth parameter, and from a three dimensional plot representing the second output of the second bandwidth detector means in relation to a calibrating input light with known values of the first actual bandwidth parameter and of the second actual bandwidth parameter.

153. The method of claim 147, further comprising:

deriving the precomputed calibration variables from a three dimensional plot representing the first output of the first bandwidth detector means in relation to a calibrating input light with known values of the first actual bandwidth parameter and of the second actual bandwidth parameter, and from a three dimensional plot representing the second output of the second bandwidth detector means in relation to a calibrating input light with known values of the first actual bandwidth parameter and of the second actual bandwidth parameter.

154. The method of claim 112, further comprising:

deriving the precomputed calibration variables from a three dimensional plot representing the first output of the first bandwidth detector means in relation to a calibrating input light with known values of the first actual bandwidth parameter and of the second actual bandwidth parameter, and from a three dimensional plot representing the second output of the second bandwidth detector means in relation to a calibrating input light with known values of the first actual bandwidth parameter and of the second actual bandwidth parameter.

155. The method of claim 149, further comprising:

deriving the precomputed calibration variables from a three dimensional plot representing the first output of the first bandwidth detector means in relation to a

calibrating input light with known values of the first actual bandwidth parameter and of the second actual bandwidth parameter, and from a three dimensional plot representing the second output of the second bandwidth detector means in relation to a calibrating input light with known values of the first actual bandwidth parameter and of the second actual bandwidth parameter.

156. The method of claim 150, further comprising:

deriving the precomputed calibration variables from a three dimensional plot representing the first output of the first bandwidth detector means in relation to a calibrating input light with known values of the first actual bandwidth parameter and of the second actual bandwidth parameter, and from a three dimensional plot representing the second output of the second bandwidth detector means in relation to a calibrating input light with known values of the first actual bandwidth parameter and of the second actual bandwidth parameter.

157. The method of claim 151, further comprising:

the first actual bandwidth parameter is an FWXM of the spectrum of light emitted from the laser; and,

the second actual bandwidth parameter is an EX of the spectrum of light emitted from the laser.

158. The method of claim 152, further comprising:

the first actual bandwidth parameter is an FWXM of the spectrum of light emitted from the laser; and,

the second actual bandwidth parameter is an EX of the spectrum of light emitted from the laser.

159. The method of claim 153, further comprising:

the first actual bandwidth parameter is an FWXM of the spectrum of light emitted from the laser; and,

the second actual bandwidth parameter is an EX of the spectrum of light emitted from the laser.

160. The method of claim 154, further comprising:

the first actual bandwidth parameter is an FWXM of the spectrum of light emitted from the laser; and,

the second actual bandwidth parameter is an EX of the spectrum of light emitted from the laser.

161. The method of claim 155, further comprising:

the first actual bandwidth parameter is an FWXM of the spectrum of light emitted from the laser; and,

the second actual bandwidth parameter is an EX of the spectrum of light emitted from the laser.

162. The method of claim 156, further comprising:

the first actual bandwidth parameter is an FWXM of the spectrum of light emitted from the laser; and,

the second actual bandwidth parameter is an EX of the spectrum of light emitted from the laser.

163. The method of claim 157, further comprising:

the first three dimensional plot provides the solution:

$(\text{first output}) = (a * (\text{calibrating input light known value of FWXM of the spectrum})) + (b * (\text{calibrating input light known value of EX of the spectrum})) + c;$   
and

the second three dimensional plot provides the solution:

$(\text{second output}) = (a * (\text{calibrating input light known value of FWXM of the spectrum})) + (b * (\text{calibrating input light known value of EX of the spectrum})) + c;$   
and

the actual bandwidth calculation apparatus uses the derived equation:

(first actual bandwidth parameter) =  $((b * (\text{second output})) - (e * (\text{first output})) + ce - bf) / (bd - ae)$ ,

or the equation:

(second actual bandwidth parameter) =  $((a * (\text{second output})) - (d * (\text{first output})) + cd - af) / (ae - bd)$ .

164. The method of claim 158, further comprising:

the first three dimensional plot provides the solution:

(first output) =  $(a * (\text{calibrating input light known value of FWXM of the spectrum})) + (b * (\text{calibrating input light known value of EX of the spectrum})) + c$ ;  
and

the second three dimensional plot provides the solution:

(second output) =  $(a * (\text{calibrating input light known value of FWXM of the spectrum})) + (b * (\text{calibrating input light known value of EX of the spectrum})) + c$ ;  
and

the actual bandwidth calculation apparatus uses the derived equation:

(first actual bandwidth parameter) =  $((b * (\text{second output})) - (e * (\text{first output})) + ce - bf) / (bd - ae)$ ,

or the equation:

(second actual bandwidth parameter) =  $((a * (\text{second output})) - (d * (\text{first output})) + cd - af) / (ae - bd)$ .

165. The method of claim 159, further comprising:

the first three dimensional plot provides the solution:

(first output) =  $(a * (\text{calibrating input light known value of FWXM of the spectrum})) + (b * (\text{calibrating input light known value of EX of the spectrum})) + c$ ;  
and

the second three dimensional plot provides the solution:

(second output) =  $(a * (\text{calibrating input light known value of FWXM of the spectrum})) + (b * (\text{calibrating input light known value of EX of the spectrum})) + c$ ;  
and

the actual bandwidth calculation apparatus uses the derived equation:

$$(\text{first actual bandwidth parameter}) = ((b * (\text{second output})) - (e * (\text{first output})) + ce - bf) / (bd - ae),$$

or the equation:

$$(\text{second actual bandwidth parameter}) = ((a * (\text{second output})) - (d * (\text{first output})) + cd - af) / (ae - bd).$$

166. The method of claim 160, further comprising:

the first three dimensional plot provides the solution:

$$(\text{first output}) = (a * (\text{calibrating input light known value of FWXM of the spectrum})) + (b * (\text{calibrating input light known value of EX of the spectrum})) + c;$$

and

the second three dimensional plot provides the solution:

$$(\text{second output}) = (a * (\text{calibrating input light known value of FWXM of the spectrum})) + (b * (\text{calibrating input light known value of EX of the spectrum})) + c;$$

and

the actual bandwidth calculation apparatus uses the derived equation:

$$(\text{first actual bandwidth parameter}) = ((b * (\text{second output})) - (e * (\text{first output})) + ce - bf) / (bd - ae),$$

or the equation:

$$(\text{second actual bandwidth parameter}) = ((a * (\text{second output})) - (d * (\text{first output})) + cd - af) / (ae - bd).$$

167. The method of claim 161, further comprising:

the first three dimensional plot provides the solution:

$$(\text{first output}) = (a * (\text{calibrating input light known value of FWXM of the spectrum})) + (b * (\text{calibrating input light known value of EX of the spectrum})) + c;$$

and

the second three dimensional plot provides the solution:

(second output) = (a \* (calibrating input light known value of FWXM of the spectrum)) + (b\* (calibrating input light known value of EX of the spectrum) +c;  
and

the actual bandwidth calculation apparatus uses the derived equation:

(first actual bandwidth parameter) = ((b \* (second output)) – (e \* (first output)) + ce – bf) / (bd – ae),

or the equation:

(second actual bandwidth parameter) = ((a \* (second output)) – (d \* (first output)) + cd – af) / (ae – bd).

168. The method of claim 162, further comprising:

the first three dimensional plot provides the solution:

(first output) = (a \* (calibrating input light known value of FWXM of the spectrum)) + (b\* (calibrating input light known value of EX of the spectrum) +c;  
and

the second three dimensional plot provides the solution:

(second output) = (a \* (calibrating input light known value of FWXM of the spectrum)) + (b\* (calibrating input light known value of EX of the spectrum) +c;  
and

the actual bandwidth calculation apparatus uses the derived equation:

(first actual bandwidth parameter) = ((b \* (second output)) – (e \* (first output)) + ce – bf) / (bd – ae),

or the equation:

(second actual bandwidth parameter) = ((a \* (second output)) – (d \* (first output)) + cd – af) / (ae – bd).

169. The method of claim 163, further comprising:

the calibrating input light known value of FWXM is FWHM and the first actual bandwidth parameter is FWHM and the calibrating input light known value of EX is E95 and the second actual bandwidth parameter is E95.

170. The method of claim 164, further comprising:

the calibrating input light known value of FWXM is FWHM and the first actual bandwidth parameter is FWHM and the calibrating input light known value of EX is E95 and the second actual bandwidth parameter is E95.

171. The method of claim 165, further comprising:

the calibrating input light known value of FWXM is FWHM and the first actual bandwidth parameter is FWHM and the calibrating input light known value of EX is E95 and the second actual bandwidth parameter is E95.

172. The method of claim 166, further comprising:

the calibrating input light known value of FWXM is FWHM and the first actual bandwidth parameter is FWHM and the calibrating input light known value of EX is E95 and the second actual bandwidth parameter is E95.

173. The method of claim 167, further comprising:

the calibrating input light known value of FWXM is FWHM and the first actual bandwidth parameter is FWHM and the calibrating input light known value of EX is E95 and the second actual bandwidth parameter is E95.

174. The method of claim 168, further comprising:

the calibrating input light known value of FWXM is FWHM and the first actual bandwidth parameter is FWHM and the calibrating input light known value of EX is E95 and the second actual bandwidth parameter is E95.

175. The method of claim 169, further comprising:

the transfer function of the first optical bandwidth detector is selected to be much more sensitive to the full width at some percent of maximum than to the content of the spectrum containing some percentage of the energy of the full spectrum and the transfer function of the second optical bandwidth detector is selected to be much more sensitive to the content of the spectrum containing some

percentage of the energy of the full spectrum than to the full width at some percent of maximum.

176. The method of claim 170, further comprising:

the transfer function of the first optical bandwidth detector is selected to be much more sensitive to the full width at some percent of maximum than to the content of the spectrum containing some percentage of the energy of the full spectrum and the transfer function of the second optical bandwidth detector is selected to be much more sensitive to the content of the spectrum containing some percentage of the energy of the full spectrum than to the full width at some percent of maximum.

177. The method of claim 171, further comprising:

the transfer function of the first optical bandwidth detector is selected to be much more sensitive to the full width at some percent of maximum than to the content of the spectrum containing some percentage of the energy of the full spectrum and the transfer function of the second optical bandwidth detector is selected to be much more sensitive to the content of the spectrum containing some percentage of the energy of the full spectrum than to the full width at some percent of maximum.

178. The method of claim 172, further comprising:

the transfer function of the first optical bandwidth detector is selected to be much more sensitive to the full width at some percent of maximum than to the content of the spectrum containing some percentage of the energy of the full spectrum and the transfer function of the second optical bandwidth detector is selected to be much more sensitive to the content of the spectrum containing some percentage of the energy of the full spectrum than to the full width at some percent of maximum.

179. The method of claim 173, further comprising:

the transfer function of the first optical bandwidth detector is selected to be much more sensitive to the full width at some percent of maximum than to the content of the spectrum containing some percentage of the energy of the full spectrum and the transfer function of the second optical bandwidth detector is selected to be much more sensitive to the content of the spectrum containing some percentage of the energy of the full spectrum than to the full width at some percent of maximum.

180. The apparatus of claim 174, further comprising:

the transfer function of the first optical bandwidth detector is selected to be much more sensitive to the full width at some percent of maximum than to the content of the spectrum containing some percentage of the energy of the full spectrum and the transfer function of the second optical bandwidth detector is selected to be much more sensitive to the content of the spectrum containing some percentage of the energy of the full spectrum than to the full width at some percent of maximum.