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FIG. 1A

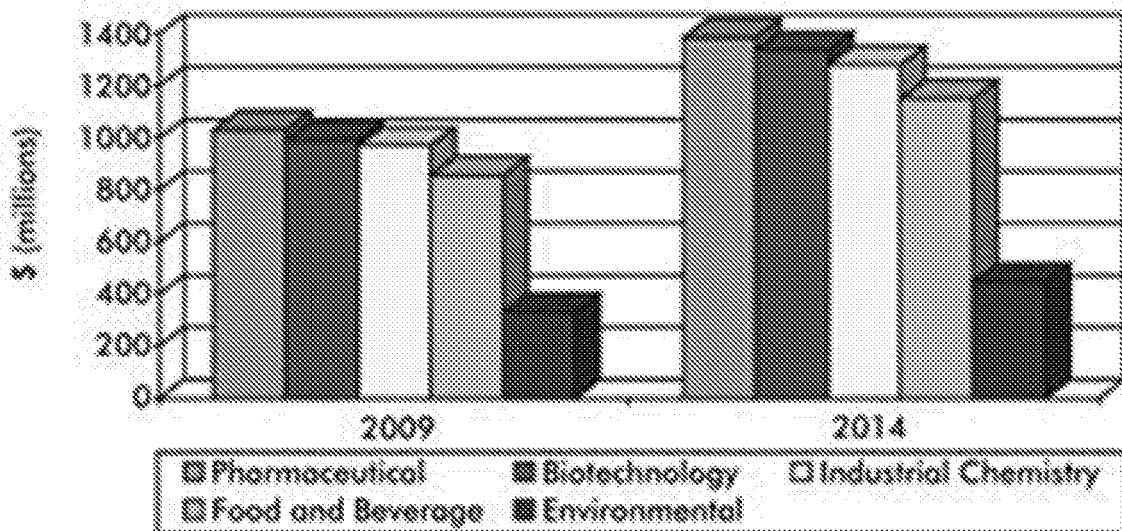
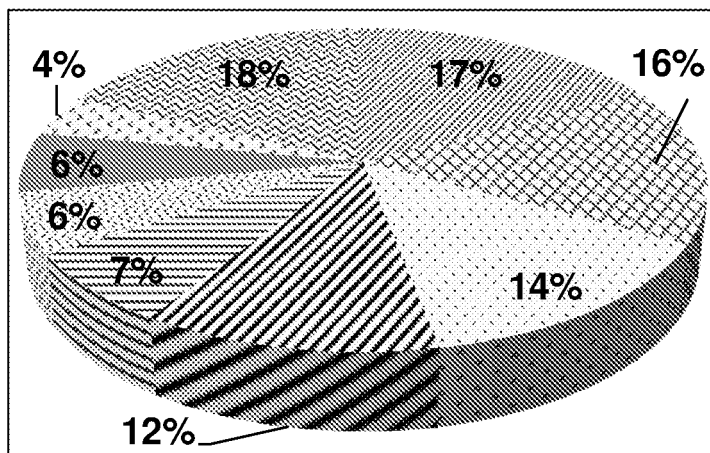
100a

FIG. 1B

100b

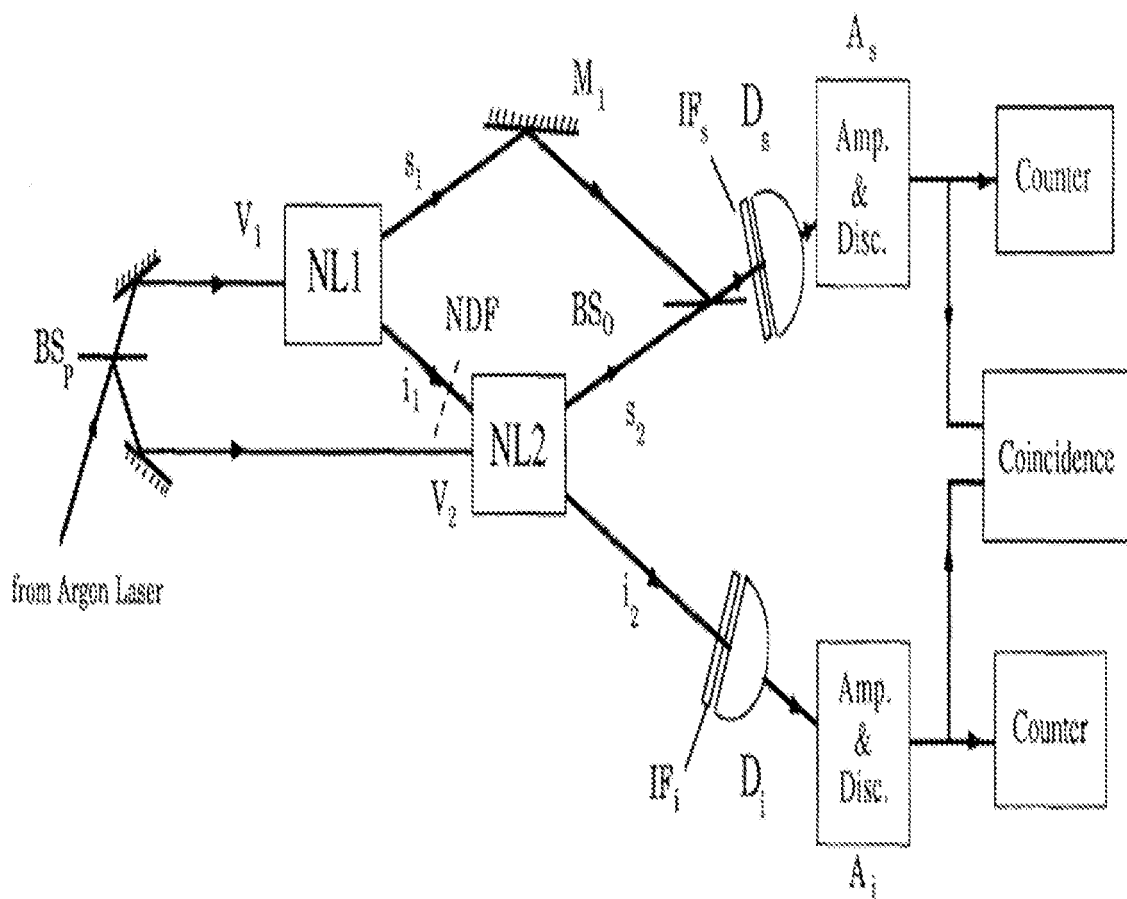
Example: Petrochemical FT-IR and FT-NIR vendor share in 2011.



Thermo Scientific – 17%  
Agilent – 16%  
PerkinElmer – 14%  
ABB – 12%  
Bruker – 7%  
AMETEK – 6%  
JASCO – 6%  
Eralytics – 4%  
Other – 18%

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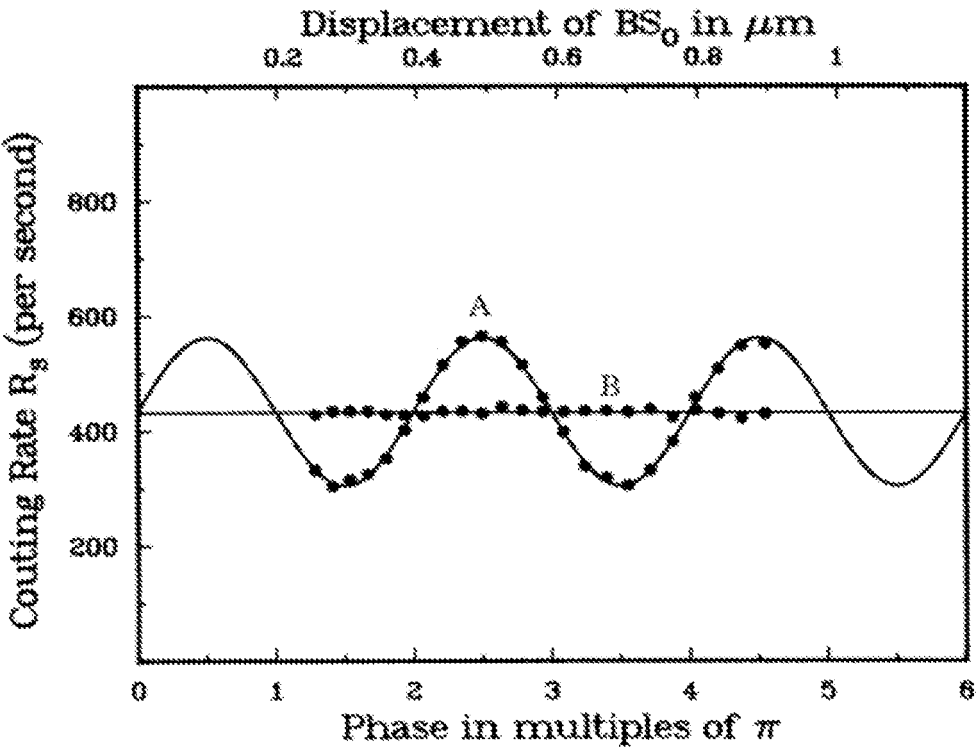
FIG. 1C

100c

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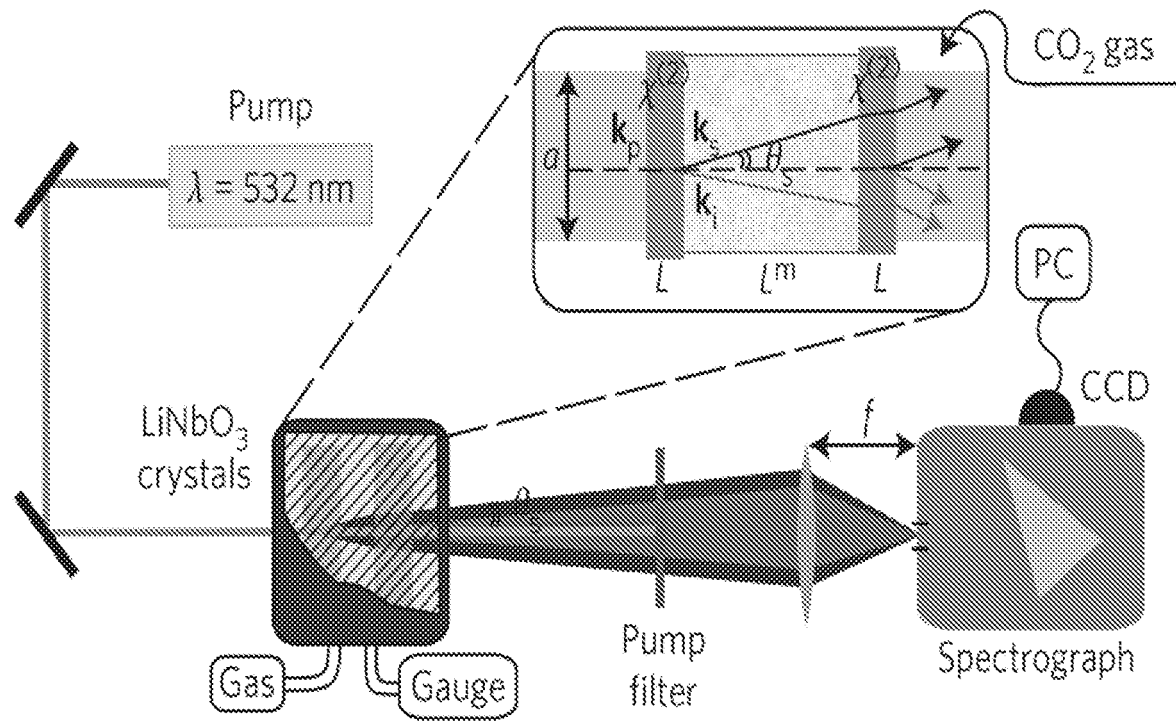
FIG. 1D

100d



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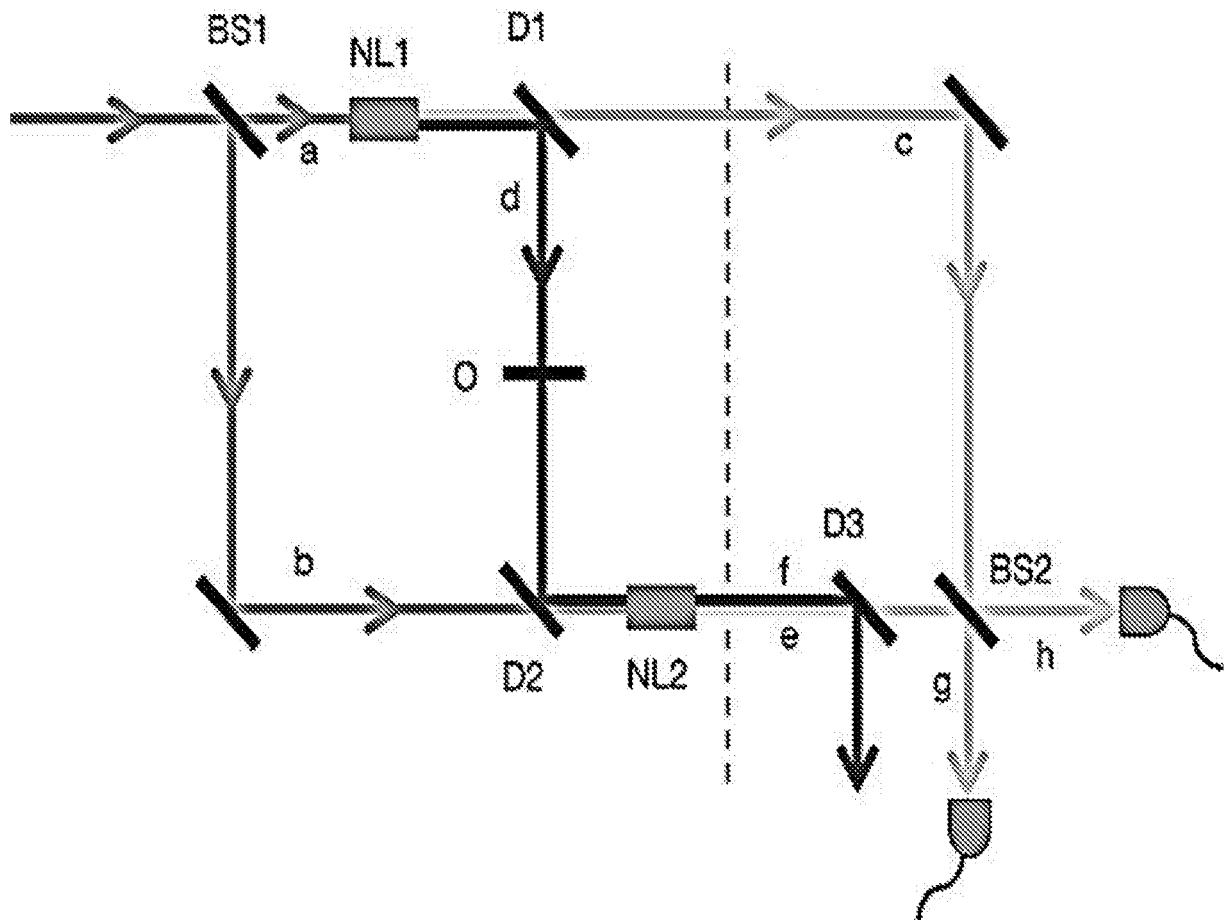
FIG. 1E

100e

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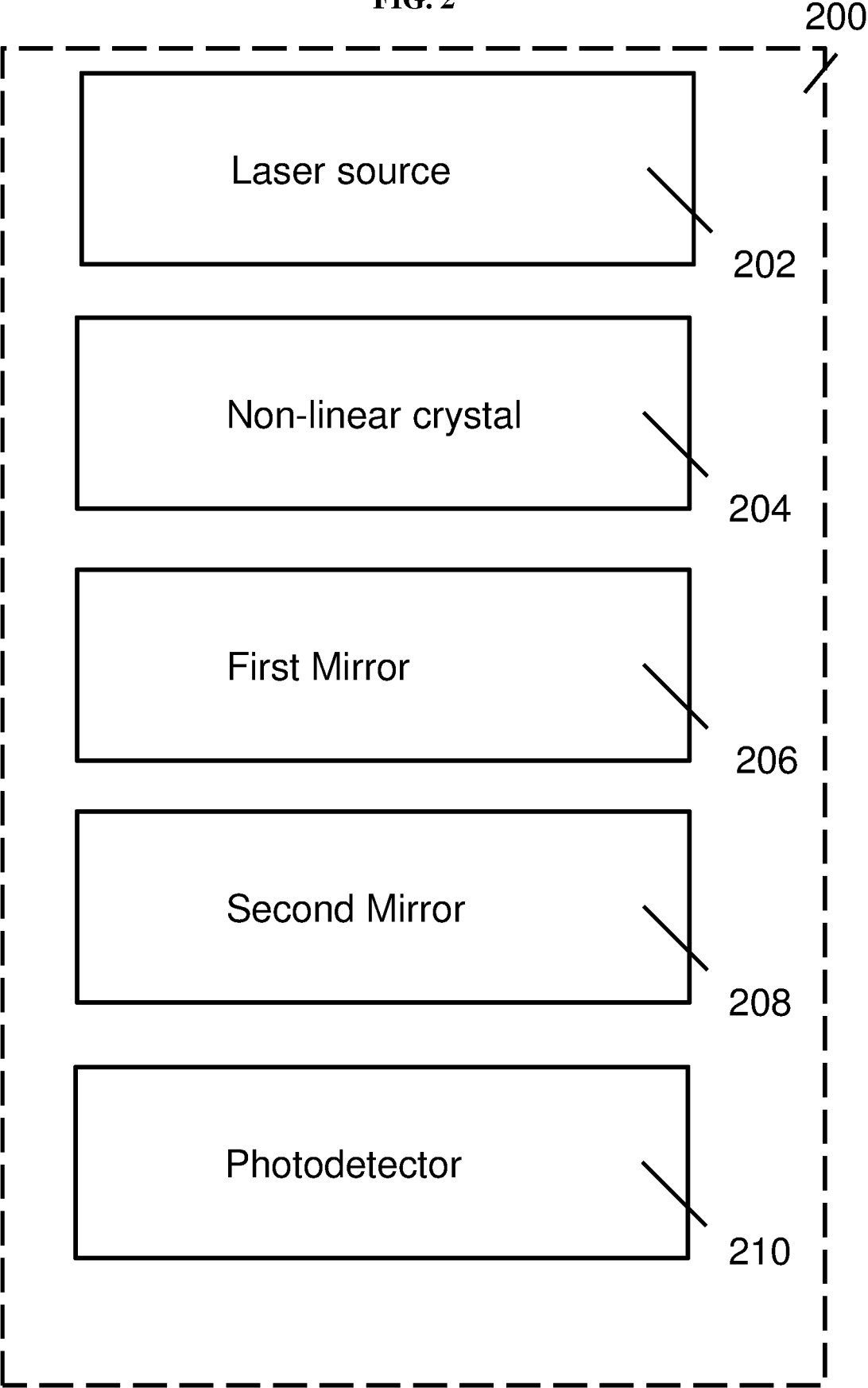
FIG. 1F

100f

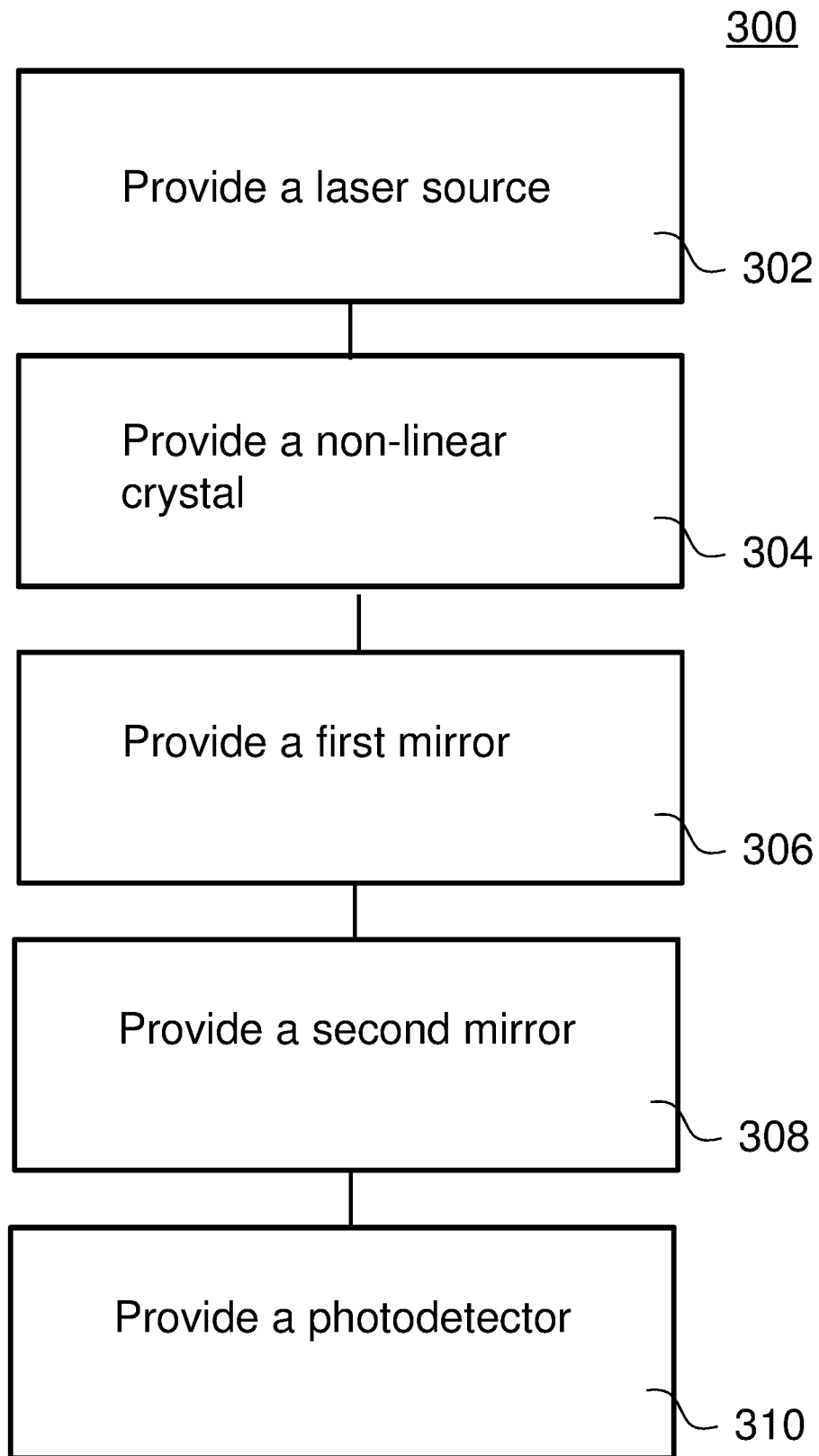


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FIG. 2



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**FIG. 3**

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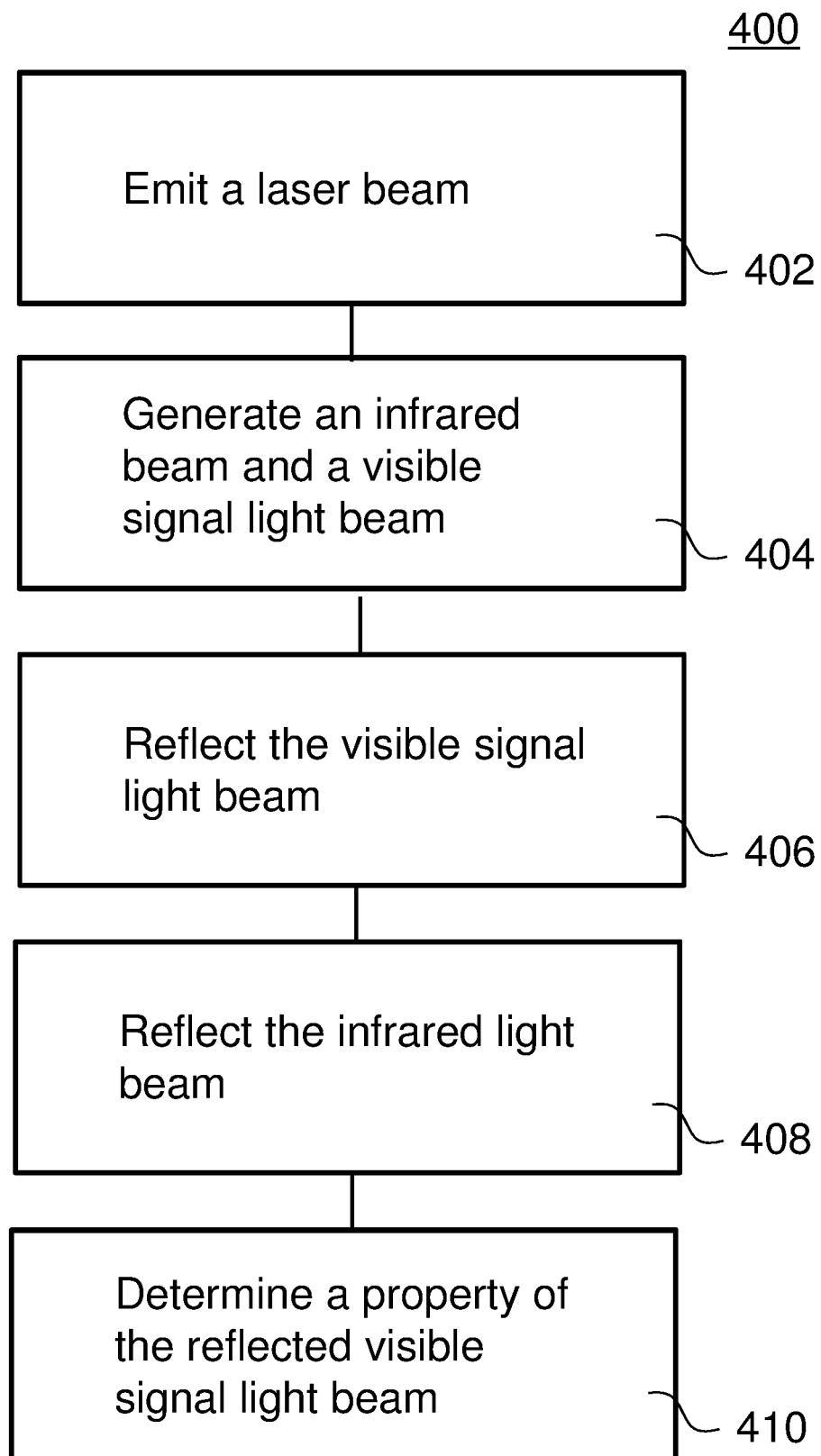
**FIG. 4**

FIG. 5A

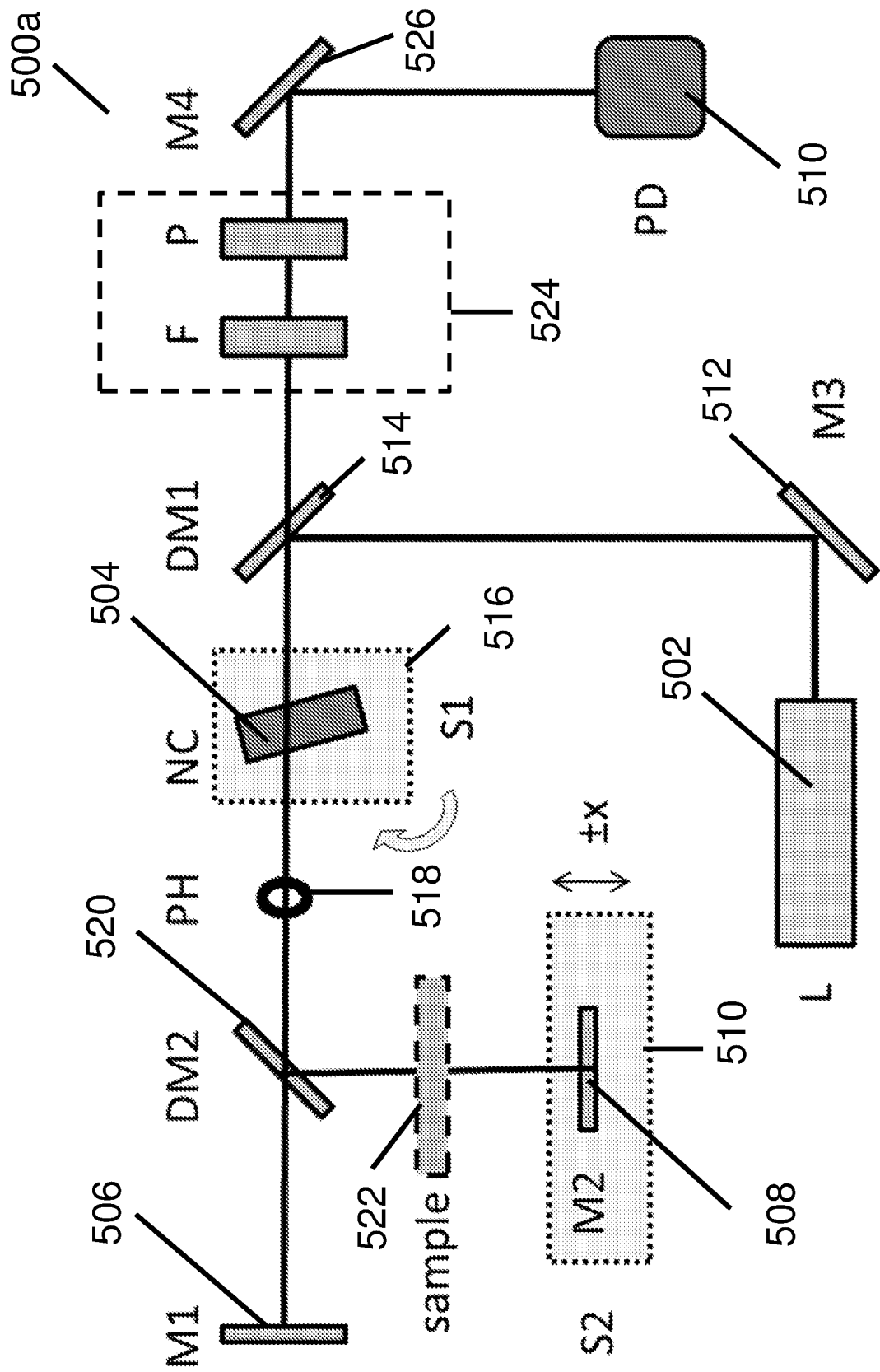


FIG. 5B

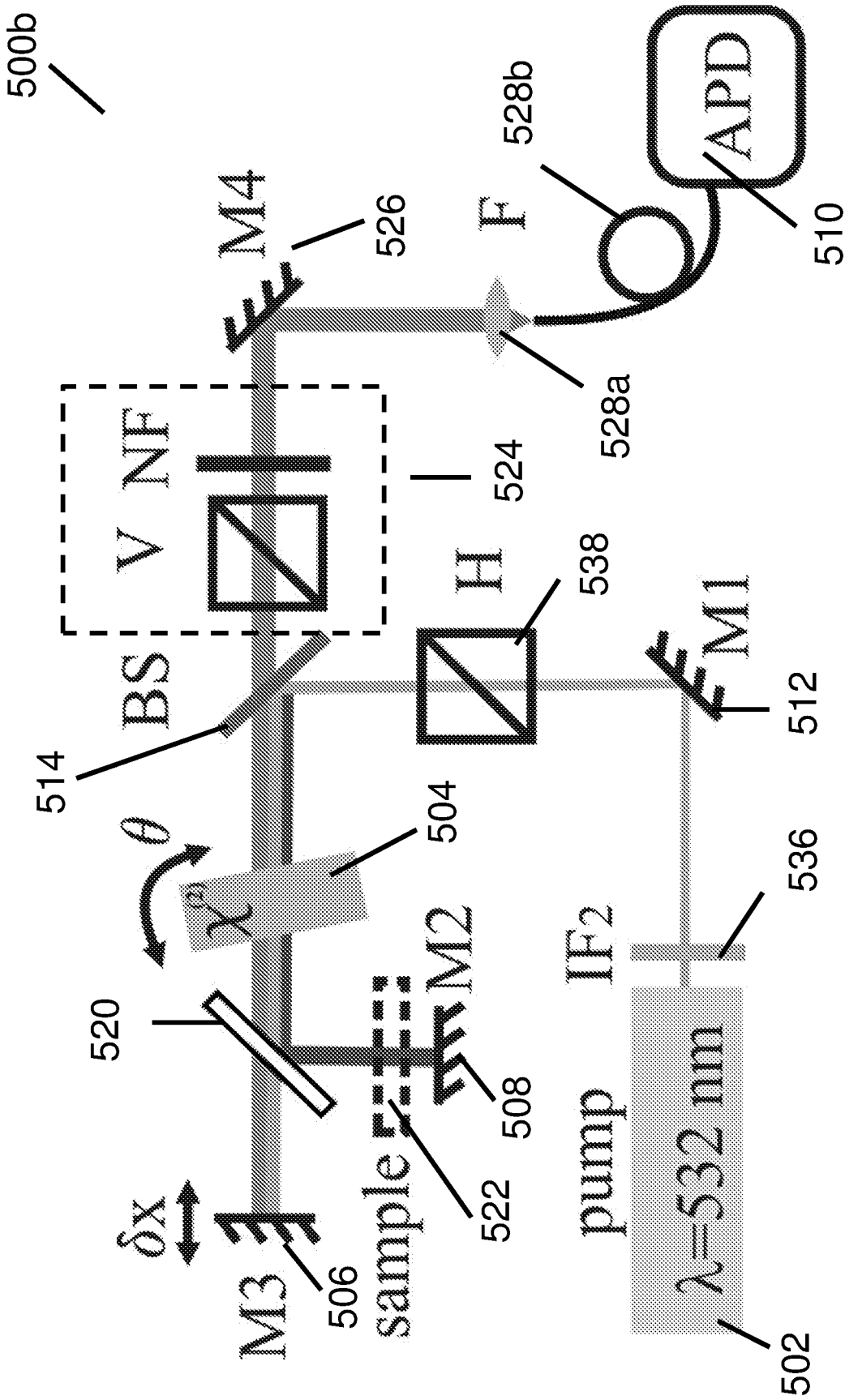
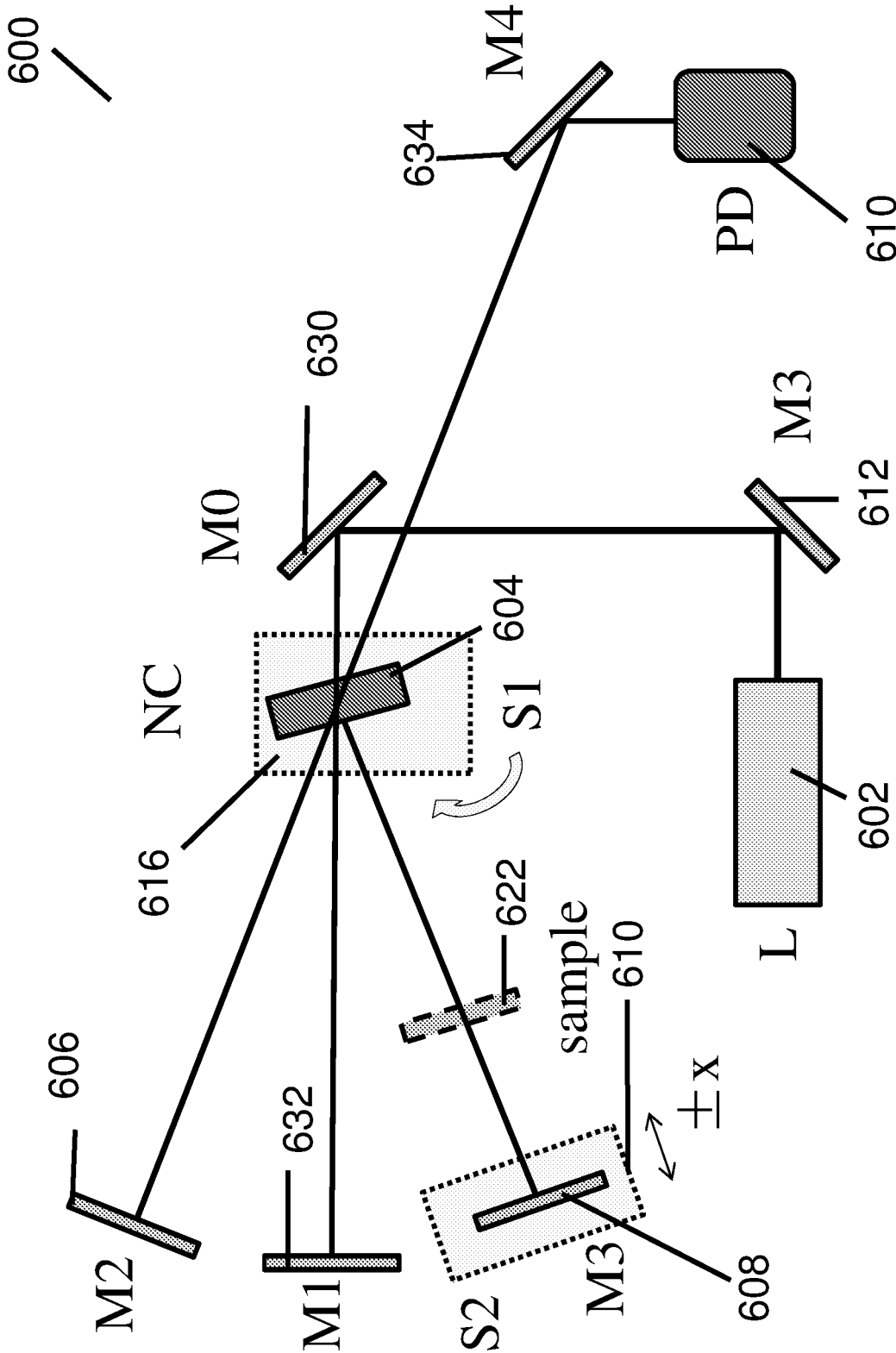
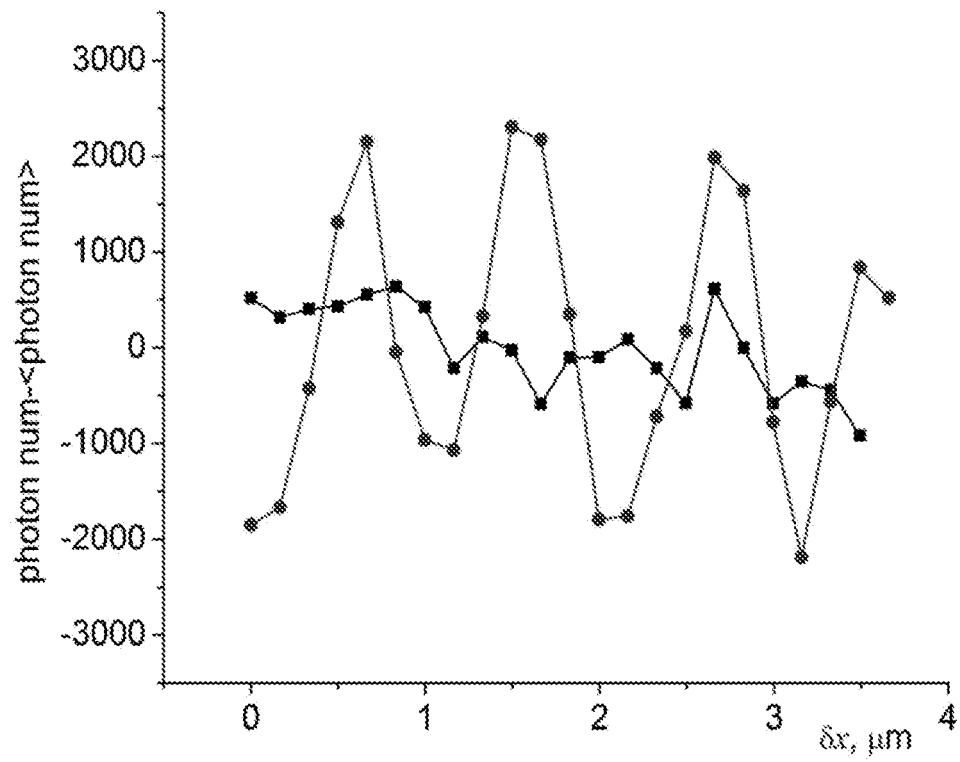


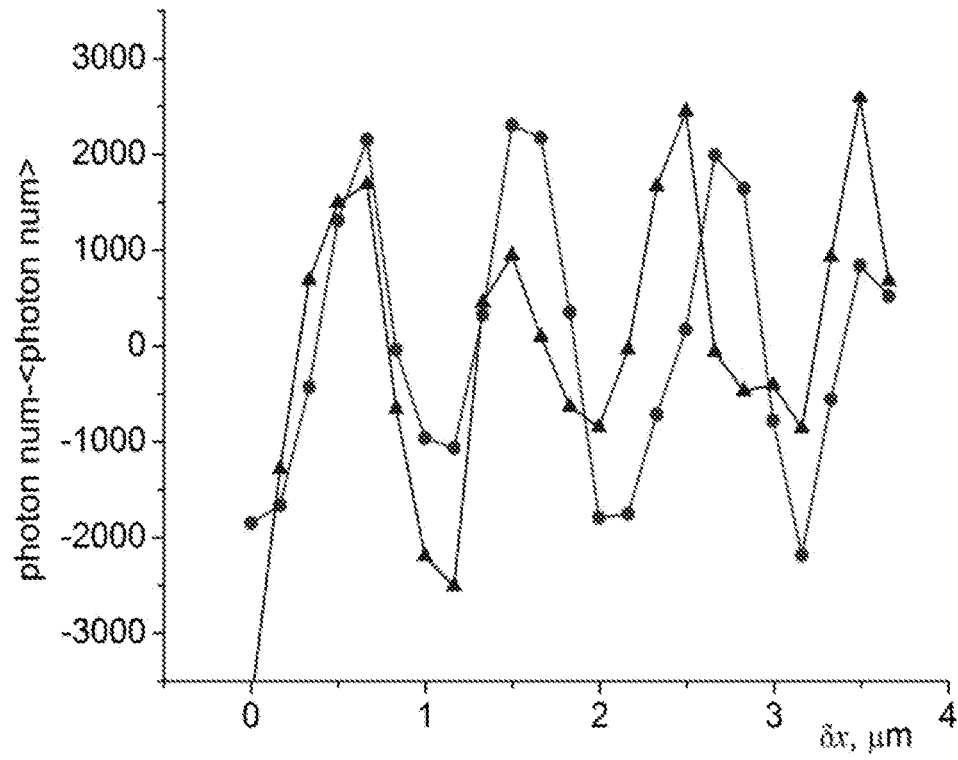
FIG. 6



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**FIG. 7A**700a

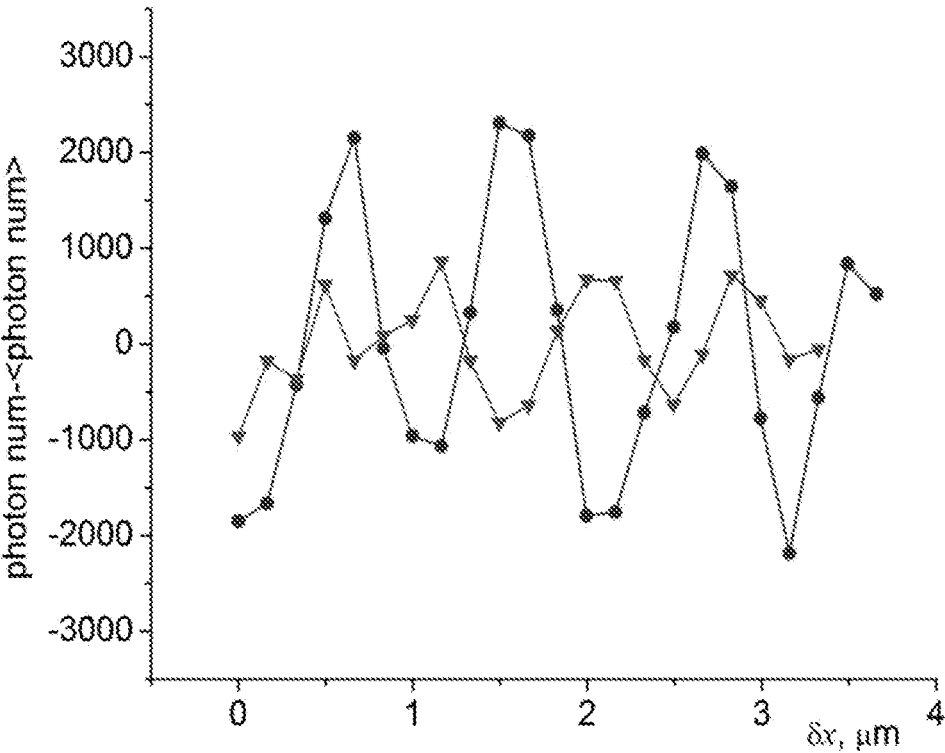
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**FIG. 7B**700b

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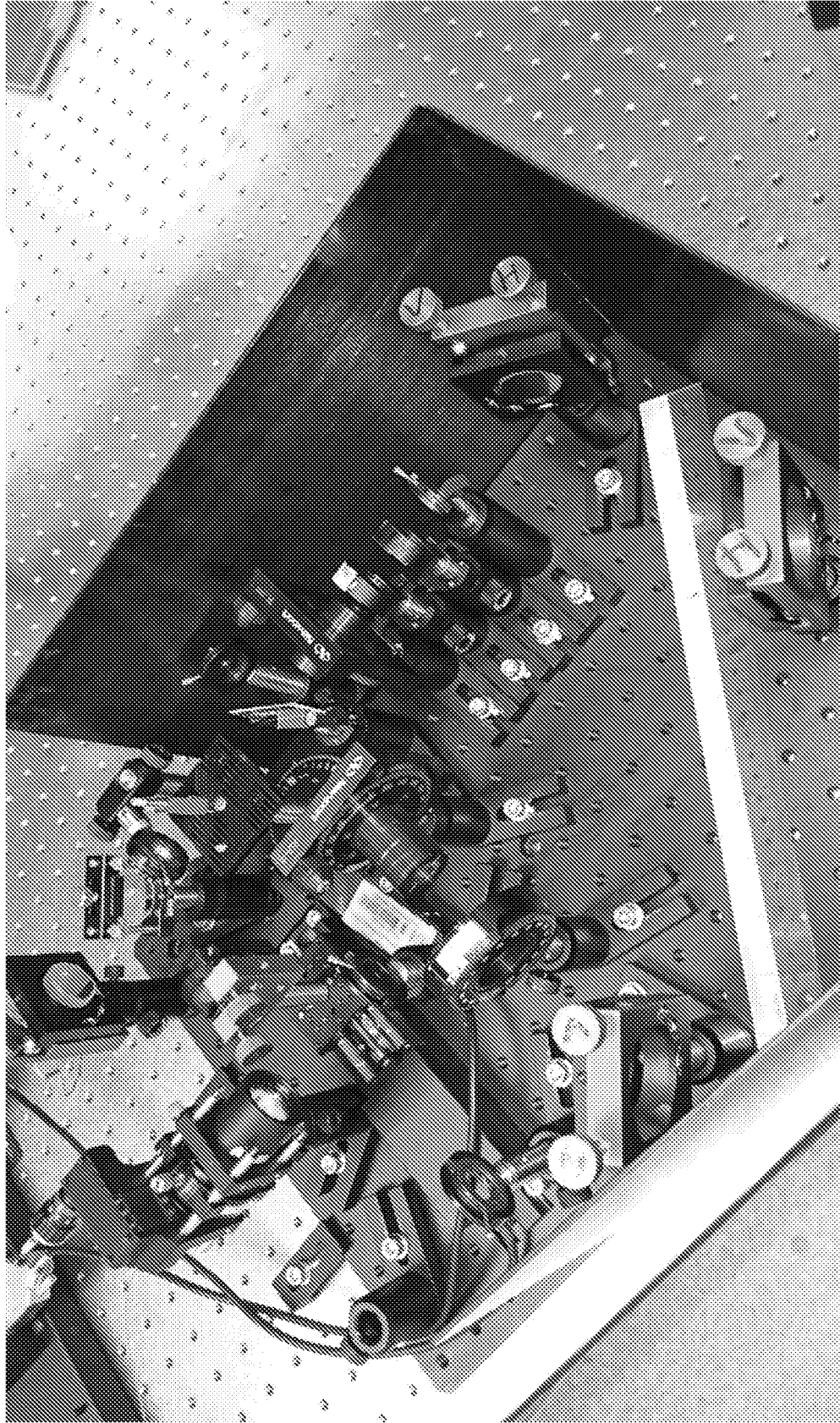
FIG. 7C

700c



700d

**FIG. 7D**



**FIG. 8A** **800a**

|                                           | <b>Competing design 1<br/>D. Kalshnikov et al.</b> | <b>Competing design 2<br/>Lemos et al.</b> | <b>Proposed design</b> |
|-------------------------------------------|----------------------------------------------------|--------------------------------------------|------------------------|
| Application to spectroscopy               | Demonstrated                                       | Not demonstrated                           | Demonstrated           |
| Knowledge of sample properties in visible | Required                                           | Not Required                               | Not Required           |
| Large interaction length                  | Limited                                            | Not limited                                | Not limited            |
| Necessity of using a CCD camera           | Required                                           | Required                                   | Not required           |
| Complexity of the setup                   | Complex                                            | Complex                                    | Simple                 |
| Footprint of the setup                    | Bulky                                              | Bulky                                      | Compact                |
| Tunability                                | Yes                                                | Yes in principle<br>(not shown)            | Yes                    |

**FIG. 8B** 800b

| Feature                      | Prior art 1 | Prior art 2 | Prior art 3 | Proposed |
|------------------------------|-------------|-------------|-------------|----------|
| Only one crystal is used     | X           | X           | X           | V        |
| Collinear regime             | X           | X           | V           | V        |
| Separated IR-beam            | X           | V           | V           | V        |
| Use of point detector        | X           | V           | X           | V        |
| No interaction with pump     | X           | V           | V           | V        |
| Single pump beam             | V           | X           | X           | V        |
| Compact (folded) design      | X           | X           | X           | V        |
| Easy to align                | X           | X           | X           | V        |
| Implementation of multi-pass | X           | hard        | hard        | easy     |

FIG. 9A 900a

| Technique                                       | FTIR                                             | Direct Spectroscopy                              | Raman Spectroscopy (a complementary method rather than a competing method) | Proposed Solution                       |
|-------------------------------------------------|--------------------------------------------------|--------------------------------------------------|----------------------------------------------------------------------------|-----------------------------------------|
| Principle of operation                          | Direct light absorption                          | Direct light absorption                          | Inelastic light scattering                                                 | Interference of down-converted light    |
| Absorption coefficient/accuracy                 | Yes<br>High                                      | Yes<br>Very high                                 | X<br>IR active vibrations cannot be detected                               | Yes<br>Very high                        |
| Refraction coefficient/accuracy                 | Yes Indirectly<br>Moderate<br>( $\sim 10^{-2}$ ) | Yes Indirectly<br>Moderate<br>( $\sim 10^{-2}$ ) | X                                                                          | Yes Directly<br>High ( $\sim 10^{-6}$ ) |
| Broadband operation                             | Yes<br>(6000 - 300 $\text{cm}^{-1}$ )            | Yes<br>(20,000 - 3000 $\text{cm}^{-1}$ )         | Defined by FT/DT spectrometer                                              | Yes<br>(7,000 ~ 700 $\text{cm}^{-1}$ )  |
| Spectral resolution                             | Very High<br>( $\sim 0.25 \text{ cm}^{-1}$ )     | High<br>( $\sim 4 \text{ cm}^{-1}$ )             | High<br>( $\sim 4 \text{ cm}^{-1}$ )                                       | High<br>( $\sim 4 \text{ cm}^{-1}$ )    |
| Need for IR equipment: source, detector, optics | YES                                              | YES                                              | YES                                                                        | NO                                      |

FIG. 9B

900b

|                                 | $\Delta\lambda$ ,<br>cm <sup>-1</sup> | Spectral<br>range,<br>cm <sup>-1</sup>                  | Advantages                                                                                                                                                                                                                                                                                        | Disadvantages                                                                                                                                                                                                                                                                                                                                              |
|---------------------------------|---------------------------------------|---------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Direct<br>spectro<br>scopy      | 3.5                                   | 20,000~<br>3,000                                        | <ul style="list-style-type: none"> <li>• Direct measurement of the spectra</li> <li>• Straightforward design</li> <li>• High signal to noise ratio (SNR) typ &gt; 50.000:1</li> <li>• Double beam configuration → removes artifacts</li> </ul>                                                    | <ul style="list-style-type: none"> <li>• Need for IR source, optics, detector → extra cost (over 50K \$)</li> <li>• Needs precise calibration</li> <li>• Sequential wavelength scan → Slow acquisition</li> <li>• Requires a slit → low signal</li> </ul>                                                                                                  |
| FTIR                            | 0.25                                  | 6,000~<br>300                                           | <ul style="list-style-type: none"> <li>• Fast parallelized readout across broad spectrum ( Fellgett advantage)</li> <li>• Does not need a slit → Good SNR typ &gt; 30.000/1 (Jacquinot advantage)</li> <li>• High accuracy due to interference of a broadband light (Connes advantage)</li> </ul> | <ul style="list-style-type: none"> <li>• Requires IR source, optics, detector → extra cost (over 20K \$)</li> <li>• Humidity and CO2 control is necessary → requires Nitrogen purging</li> <li>• Artefacts arising from interferogram</li> <li>• Requires a locking laser</li> <li>• All components are detected at the same time → extra noise</li> </ul> |
| Nonlinear<br>interfer<br>ometer | 4                                     | 20,000~<br>7,000<br>(extenda<br>ble to<br>THz<br>Range) | <ul style="list-style-type: none"> <li>• Directly reveals refractive index and absorption coefficients</li> <li>• No need for IR equipment → Economical</li> <li>• Does not need purging with Nitrogen from source to the detector</li> <li>• Extendable towards THz range (Far-IR)</li> </ul>    | <ul style="list-style-type: none"> <li>• The operation range is limited by IR absorption in a nonlinear crystal</li> <li>• Sequential wavelength scan</li> <li>• Sample should be transparent in VIS</li> <li>• Knowledge of refractive index in visible</li> <li>• Pump laser may damage the sample</li> <li>• Limited sensitivity</li> </ul>             |