

Se rial Number 980,020

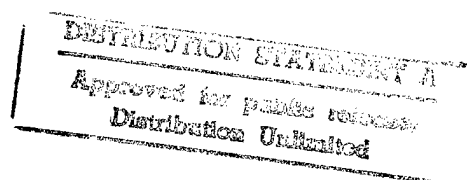
Filing Date 26 November 1997

Inventor David T. Schaafsma
 Jasbinder S. Sanghera
 Ishwar D. Aggarwal

NOTICE

The above identified patent application is available for licensing. Requests for information should be addressed to:

OFFICE OF NAVAL RESEARCH
DEPARTMENT OF THE NAVY
CODE OCCC
ARLINGTON VA 22217-5660



19980120 112

DTIC QUALITY INSPECTED 8

Serial No.:

Inventors: David T. Schaafsma
Jasbinder S. Sanghera
Ishwar D. Aggarwal

Patent Application
Navy Case No. 78,344

1 INFRARED OPTICAL FIBER COUPLER

2

3 BACKGROUND OF THE INVENTION

4

5 1. Field of the Invention

6 The present invention relates to fiber optic couplers and
7 particularly to a novel infrared fiber optic coupler, useful in
8 multiplexing and demultiplexing optical data, creating components
9 for communications systems including add/drop devices, amplifiers
10 and oscillators, making hybrid or multi-element sensors, and for
11 fiber interferometry. Optical couplers represent one of the
12 fundamental building blocks for sophisticated optical fiber
13 devices, which have not yet been made for mid-infrared (about
14 1.5-12 μm) operation.

15

16 2. Description of the Related Art

17 Many processes exist and are employed to make fiber coupler
18 devices which are suited for operation in the visible spectrum or
19 the near-infrared ($< 1.6 \mu\text{m}$), most commonly utilizing silica
20 fibers; the fusion technique has been employed in making fiber
21 couplers from silica glass fibers for over two decades. Yet
22 these kind of devices are not available in the mid-infrared at
23 present, largely due to the lack of methodology and knowledge for
24 making basic components such as couplers from chalcogenide or

Serial No.:

Inventors: David T. Schaafsma
Jasbinder S. Sanghera
Ishwar D. Aggarwal

Patent Application
Navy Case No. 78,344

1 other infrared-transmitting glass fibers, and due to the
2 inadequate quality of the fiber that has been produced in the
3 past.

4 With the availability of high-quality chalcogenide fiber,
5 the fabrication of these devices has become feasible. Just as
6 chalcogenide fibers have advantages in the infrared over standard
7 silica glass fibers, devices made from these infrared fibers
8 should show marked performance improvement over any device made
9 with silica fiber. Infrared fiber devices, using fiber couplers,
10 can now be fabricated for applications in chemical sensing, data
11 transmission, and infrared spectroscopy.

12 There are three common elements to the majority of coupler
13 fabrication processes which utilize thermal fusion: etching or
14 surface preparation, heating, and mechanical bonding. There are
15 several important differences in fusion coupling (defined as
16 heating and mechanical bonding) of chalcogenide glasses versus
17 silica glass, which can be summarized as follows:

18 1. Etching and Surface Preparation

19 a) Chalcogenide compounds cannot be etched with
20 hydrofluoric acid, as is the common practice with silicates.
21 Alternative etchants such as KOH must be used.

22 b) In silicates, the surface oxidation is not a major
23 concern during the fusion process, since most of these compounds

Serial No.:

Inventors: David T. Schaafsma
Jasbinder S. Sanghera
Ishwar D. Aggarwal

Patent Application
Navy Case No. 78,344

1 contain oxygen as a primary constituent. In chalcogenides,
2 surface oxides form an entirely new compound which inhibits
3 wetting, surface contact, and which form an optical barrier in
4 the waveguide. This layer can be removed in a reactive
5 atmosphere or by plasma treatment.

6 2. Thermal Mechanics

7 a) The melting and softening temperatures of the
8 chalcogenide glass are substantially lower than the melting
9 temperature of silica, so open flame heating systems cannot be
10 used.

11 b) Chalcogenides are much more susceptible to
12 oxidation than silica, and thus the process must be performed in
13 an inert atmosphere, other than oxygen-containing atmospheres
14 (e.g. halogen atmospheres).

15 c) The viscosity profile as a function of temperature
16 is steeper in chalcogenides than in silica, so the range of
17 temperatures over which the fusion can be achieved is narrower.
18 The temperature or viscosity range for the fusion process is
19 particularly important since these chalcogenide compositions are
20 highly susceptible to interdiffusion of the core and cladding
21 material at elevated temperatures.

22 d) The higher vapor pressure of chalcogenides at
23 elevated temperatures leads to greater volatilization of the

Serial No.:

Inventors: David T. Schaafsma
Jasbinder S. Sanghera
Ishwar D. Aggarwal

Patent Application
Navy Case No. 78,344

1 glass constituents, the loss of which impairs the optical and
2 mechanical performance of the fiber. This means that close
3 control of temperature in this process is important and
4 necessary.

5 3. Mechanical Considerations

6 a) The more fragile chalcogenide fiber requires
7 different handling and tensioning procedures than mandated by the
8 established silica process, particularly when twisted to achieve
9 overlap between the fibers.

10 b) The compositional range of the chalcogenide
11 glasses allows for a greater variation in the numerical aperture
12 of the fiber, which determines the magnitude of the evanescent
13 field outside the core. Since the coupling in these devices is
14 largely evanescent, and driven by bends or twists in the fiber
15 where light can escape more easily, this variability means that
16 the chalcogenide fiber coupler fabrication process can tolerate a
17 wider range of bend radii in the fiber and hence more or fewer
18 twists of the fiber.

19 c) The higher refractive index of chalcogenide glass
20 ensures greater light guiding even in core-only material, so that
21 slight air gaps in the coupler body result in much lower losses.
22

23 A multimode "coupler" made from chalcogenide glass has been

Serial No.:

Inventors: David T. Schaafsma
Jasbinder S. Sanghera
Ishwar D. Aggarwal

Patent Application
Navy Case No. 78,344

1 fabricated previously, but this device employed core-only fiber,
2 and did not actually fuse the fibers together. The performance
3 of this device is also affected by atmospheric conditions. The
4 device described in this application uses core-clad fiber, which
5 has inherently lower losses and is greatly preferred over
6 core-only fiber in making sensing and communications devices.

8 SUMMARY OF THE INVENTION

9
10 Accordingly, it is an object of the present invention to
11 provide a new infrared fiber optic coupler and a method for
12 making the new infrared fiber optic coupler.

13 Another object of the invention is to provide an infrared
14 fiber optic coupler in which two infrared light beams can be
15 placed in the same infrared transmitting fiber.

16 A further object of the invention is to provide an infrared
17 fiber optic coupler which can split one infrared light beam into
18 two infrared light beams.

19 These and other objects of this invention are achieved by
20 providing an infrared fiber optic coupler and a method for making
21 an infrared fiber optic coupler. The method comprises the steps
22 of: braiding first and second infrared transmitting glass fibers
23 to form first and second arms of the infrared fiber optic

Serial No.:

Inventors: David T. Schaafsma
Jasbinder S. Sanghera
Ishwar D. Aggarwal

Patent Application
Navy Case No. 78,344

1 coupler; inserting the braided first and second infrared
2 transmitting glass fibers through a furnace; securing the braided
3 glass fibers by two clamping mechanisms on first and second sides
4 of the furnace; purging the furnace of water vapor and oxygen
5 with a steady flow of inert gas through the furnace; allowing
6 infrared light to pass through one of the first and second arms
7 of the coupler; detecting the infrared signals from the first and
8 second arms of the coupler in first and second infrared
9 detectors; comparing the detected signals to develop a coupling
10 ratio between the first and second arms of the coupler; turning
11 the furnace on to heat the first and second braided glass fibers
12 to the point where the glass fibers begin to darken in color;
13 translating the second clamping mechanism to produce a tautness
14 on the first and second braided glass fibers until the desired
15 coupling ratio has been achieved; turning the furnace off;
16 maintaining tension on the first and second braided glass fibers
17 until the fibers cool to rigidity; and turning off the gas flow.

18
19 Brief Description of the Drawings

20 These and other objects, features and advantages of the
21 invention, as well as the invention itself, will become better
22 understood by reference to the following detailed description
23 when considered in connection with the accompanying drawings

Serial No.:
Inventors: David T. Schaafsma
Jasbinder S. Sanghera
Ishwar D. Aggarwal

Patent Application
Navy Case No. 78,344

1 wherein like reference numerals designate identical or
2 corresponding parts throughout the several views and wherein:

3 Fig. 1 illustrates an apparatus for making and testing a
4 fused multimode fiber coupler (135 μm $\text{As}_{40}\text{S}_{59}\text{Se}_2$ core, 200 μm
5 $\text{As}_{40}\text{S}_{60}$ cladding);

6 Fig. 2 illustrates exemplary fiber material compositions of
7 chalcogenide and chalcohalide based infrared optical fibers,
8 including fibers doped with rare earths or transition metals;

9 Figs. 3A, 3B and 3C show images useful in explaining the
10 operation of the apparatus of Fig. 1;

11 Fig. 4 illustrates an example of how the manufacturing
12 process shown in Fig. 1 can be automated; and

13 Fig. 5 illustrates an exemplary manufactured MxN infrared
14 optical fiber coupler.

15
16 Detailed Description of the Preferred Embodiment

17 Referring now to the drawings, a fused multimode fiber
18 coupler 39 (135 μm $\text{As}_{40}\text{S}_{59}\text{Se}_2$ core, 200 μm $\text{As}_{40}\text{S}_{60}$ cladding) was
19 made and tested using the apparatus shown in Fig. 1. It should
20 be noted at this time that this same technique is also applicable
21 to singlemode chalcogenide fiber and to chalcohalide
22 compositions, including fibers doped with rare earths or
23 transition metals.

Serial No.:
Inventors: David T. Schaafsma
Jasbinder S. Sanghera
Ishwar D. Aggarwal

Patent Application
Navy Case No. 78,344

1 Before the operation of the apparatus of Fig. 1 is
2 discussed, additional information on chalcogenide and
3 chalcohalide glasses will now be discussed. Components of
4 exemplary fiber material glass compositions of chalcogenide-based
5 infrared optical fibers are shown in Fig. 2A, while components of
6 exemplary fiber glass compositions of chalcohalide-based infrared
7 optical fibers are shown in Fig. 2B.

8
9 As indicated in Fig. 2A, the chalcogenide glass compositions
10 include any glass composed of at least one of the anions sulfur
11 (S), selenium (Se) and tellurium (Te) and at least one suitable
12 cation, including but not limited to barium (Ba), germanium (Ge),
13 indium (In), arsenic (As), gallium (Ga), or lanthanum (La) in
14 binary, ternary, quaternary, etc. mixtures. Example chalcogenide
15 glass compositions include As_4S_{60} , $As_{40}S_{55}Se_5$, and $Ge_{33}As_{12}Se_{55}$.

16
17 As indicated in Fig. 2B, the chalcohalide glass compositions
18 include any glass composed of at least one of each of the
19 aforementioned cations and anions, plus at least one of the
20 halides (but less than a total of 50 weight percent) of chlorine
21 (Cl), fluorine (F), bromine (Br) and iodine (I).

22 It is intended that all compositions of the chalcogenide and
23 chalcohalide glasses that form a stable glass are included in the

Serial No.:
Inventors: David T. Schaafsma
Jasbinder S. Sanghera
Ishwar D. Aggarwal

Patent Application
Navy Case No. 78,344

1 claimed invention.

2
3 Referring back to Fig. 1, in operation, fibers 17 and 19 are
4 either bare fibers or coated fibers that have been stripped and
5 cleaned, at least over the portion which will form a new infrared
6 fiber optic coupler 39 when subsequently heated. The fibers 17
7 and 19 are braided and threaded through a resistively-heated
8 furnace 23, which is purged with a steady flow of inert gas, such
9 as nitrogen, from a small tube 27. A heater winding 24 is coiled
10 around a center portion of the outer circumference of the furnace
11 23. The furnace 23 was made from ordinary silica tubing and
12 measured approximately 5 centimeters (cm) in length, with a hot
13 zone (heater winding 24) of approximately 2 cm. The current into
14 the heater winding 24 of the furnace 23 was controlled by a
15 standard DC current supply 25 and the temperature was read with a
16 0.2 mm gauge Pt-Rh (platinum-rhodium) thermocouple 29.

17 The fibers 17 and 19 were held securely by two clamping
18 mechanisms 21 and 31 on either side of the furnace 23, with the
19 exemplary clamping mechanism 31 being attached to a translation
20 stage 33. The translation stage 33 is capable of translating the
21 clamping mechanism 31, and therefore the fibers 17 and 19, in the
22 directions of arrows 32 in order to produce tension in the fibers
23 17 and 19. Such translation can be accomplished by manually

Serial No.:

Inventors: David T. Schaafsma
Jasbinder S. Sanghera
Ishwar D. Aggarwal

Patent Application
Navy Case No. 78,344

1 moving the translation stage 32, by turning a micrometer (not
2 shown) or a screw adjustment (not shown), or by any other
3 suitable means. Due to the fragility of the chalcogenide glass,
4 it is preferrable in this case to braid the fibers 17 and 19
5 before clamping them, rather than twisting them in situ as is
6 normally done with silica fibers.

7 The measurement of the optical properties of the coupler 39
8 being made is achieved with the use of detectors 35 and 37, one
9 for each arm of the coupler 39, and an infrared source or a
10 wideband optical source 11 to couple light from the light source
11 11 through the objective lens 15 into the input fiber arm 17 of
12 the coupler 39. In this case, an exemplary laser operating at
13 2.65 μm was used as the light source 11, and the signal from the
14 light source 11 was modulated or chopped by chopper 13 and read
15 by InSb (indium antimonide) or MCT (mercury, cadmium, telluride)
16 detectors 35 and 37 and fed into lock-in amplifiers 41 and 43 to
17 obtain voltage readings for the outputs of detectors 35 and 37.
18 The voltage outputs of the lock-in amplifiers 41 and 43 were then
19 applied to a ratiometer 45 to develop the coupling ratio of the
20 coupler 39. The detectors 35 and 37 were calibrated against each
21 other to eliminate detector errors.

22 After the purge flow had been established and allowed to run
23 for some time to thoroughly rid the chamber of the furnace 23 of

Serial No.:

Inventors: David T. Schaafsma
Jasbinder S. Sanghera
Ishwar D. Aggarwal

Patent Application
Navy Case No. 78,344

1 water vapor and oxygen, the furnace 23 was turned on to heat the
2 fibers 17 and 19. Both fibers 17 and 19 should be taut but not
3 tensioned when the heat cycle begins. The fibers 17 and 19
4 should then be heated to the point where the glass just begins to
5 darken (turning from semi-translucent to opaque or from red to
6 slightly dark for the glass specified here), a temperature of
7 approximately 250 degrees C. Care must be taken not to allow the
8 fibers 17 and 19 to sag too much while the fibers soften. This
9 must be determined for each fiber composition.

10 When the fibers 17 and 19 begin to be heated, they start to
11 fuse together at the portion of those fibers that is being heated
12 by the heater winding 24. At this time, light in the fiber 17
13 begins to be coupled into the fiber 19 to begin to establish a
14 coupling ratio between the fibers 17 and 19, as indicated by the
15 ratiometer 45.

16 Once the fibers 17 and 19 have softened sufficiently,
17 tension should be applied and allowed to continue until the
18 desired coupling ratio, such as 2:1 or 3:1 has been read out of
19 the ratiometer 45. Real-time monitoring is accomplished easily
20 by injecting the probe beam while the fusing is being done. To
21 stop the fusion process, the furnace 23 should be turned off and
22 the tension on the fibers 17 and 19 maintained for a short time
23 until the fibers 17 and 19 cool to rigidity. When the fibers 17

Serial No.:

Inventors: David T. Schaafsma
Jasbinder S. Sanghera
Ishwar D. Aggarwal

Patent Application
Navy Case No. 78,344

1 and 19 have changed back to their original color, the fibers 17
2 and 19 have cooled to rigidity and the tension should be removed
3 from the fibers 17 and 19 and the nitrogen purge flow can be
4 stopped. Rapid shutoff of the heat is obviously desirable when a
5 precise coupling ratio is needed.
6

7 Using this system, the inventors have achieved a 3.3:1
8 infrared optical fiber coupler with less than 0.3 dB insertion
9 loss. Shown in Fig. 3 are images of the fiber 17 and 19 outputs
10 in Fig. 1 before and after the fusion process, showing that the
11 guided mode in the fiber 17 (Fig. 3A) retains its character in
12 both the direct (Fig. 3B) and split-off (Fig. 3C) beams after the
13 fibers 17 and 19 have been fused.

14 More specifically, Fig 3A shows the infrared image of the
15 light (direct beam) in the fiber 17 before the fusion process,
16 showing the light guided in the core of the fiber 17.

17 Fig. 3B shows the infrared image of the beam coming out of
18 the direct arm 17 of the coupler 39 after the fibers 17 and 19
19 were fused. The core image is saturated to allow identification
20 of the cladding layer.

21 Fig. 3C shows the infrared image of the split beam, coupled
22 into the second arm 19 of the coupler 39, showing how the guided
23 modes have been preserved.

Serial No.:
Inventors: David T. Schaafsma
Jasbinder S. Sanghera
Ishwar D. Aggarwal

Patent Application
Navy Case No. 78,344

1 Referring now to Fig. 4, the technique discussed in Figs. 1,
2 2A, 2B and 3A, 3B and 3C is highly amenable to automation of the
3 manufacturing process, as shown in Fig. 4. Temperature control
4 of the furnace 51 (similar in construction and operation to the
5 furnace 23 in Fig. 1) and tensioning of the fibers 53 and 55
6 (similar to the fibers 17 and 19 in Fig. 1) can be accomplished
7 through well-established industrial control techniques (not
8 shown) and these controls can even be linked to direct, real-time
9 readout of the coupling ratio from a ratiometer (similar in
10 construction and operation to the ratiometer 45 in Fig. 1). The
11 fibers 53 and 55 can be fed from one or more spools 57 into the
12 furnace 59, while infrared light from an infrared source or a
13 wideband light source (not shown, but similar to the infrared
14 light source 11 of Fig. 11) can be injected into the opposite end
15 of the spool 57, and the heating process is similar to that
16 discussed in regard to Fig. 1. Once the fusion process is
17 complete, a small capstan or takeup spool 65 is the automated
18 means that can be used to pull the fibers 53 and 55 (having been
19 fused to form a coupler) through the furnace 59, optionally into
20 a cell or casing 63 where a protective shell can be cemented
21 around the fibers 53 and 55. When the fibers 53 and 55 have been
22 drawn far enough to allow the desired pigtail length, a cleaving
23 mechanism 61 can be used to separate the finished infrared fiber

Serial No.:

Inventors: David T. Schaafsma
Jasbinder S. Sanghera
Ishwar D. Aggarwal

Patent Application
Navy Case No. 78,344

1 optic coupler package from the rest of the spool 57. A new casing
2 63 is then inserted between the furnace 51 and the capstan 65 to
3 allow the process to continue on to the next infrared fiber optic
4 coupler package to be fabricated.

5 Each time that an infrared fiber optic coupler has been
6 completed (with the fibers 53 and 55 cooled and no longer being
7 stretched), a setting agent 64, such as an epoxy, is inserted
8 into the coupler casing 63 to hold the fibers 53 and 55 in the
9 coupler casing 63 and make the fiber coupler package. Any
10 setting agent is suitable as long as it is relatively quick-
11 hardening and does not significantly absorb light in the
12 wavelength region of operation where the coupler is to be
13 operated.

14
15 Fig. 5 illustrates an exemplary manufactured MxN infrared
16 optical fiber coupler, showing M fiber inputs 75 held in place
17 inside the coupler 82 by epoxy 79 and with N fiber outputs 83.

18
19 ADVANTAGES AND NEW FEATURES OF THE INFRARED OPTICAL FIBER COUPLER

20
21 These couplers will allow more sophisticated optical devices
22 in the mid-infrared region. Two examples of possible devices
23 using these couplers are as follows:

Serial No.:
Inventors: David T. Schaafsma
Jasbinder S. Sanghera
Ishwar D. Aggarwal

Patent Application
Navy Case No. 78,344

1 Example 1.

2 All-fiber Fourier transform infrared spectrometer (AFFTIR).

3 By using one or two fiber couplers an interferometer
4 (Michelson or Mach-Zender, respectively) can be made completely
5 from lengths of infrared fiber. One fiber can be stretched
6 slightly using a mechanical system to produce a temporal
7 interferogram. If another length of fiber is exposed to the
8 ambient environment, Fourier transform spectroscopy (FTS) can be
9 achieved using the evanescent coupling from the fiber. FTS is
10 commonly used for chemical sensing, meteorology, solar science,
11 and atmospheric chemistry, among other things.

12 Example 2.

13 Fiber evanescent array detector (FEAD).

14 With either a cascade network of 1x2 fiber couplers or a
15 single 1xN coupler, an array of evanescent fiber sensors can be
16 fabricated. Such a device would be useful for micro-topological
17 monitoring or active sensing of flow streams or even as a
18 multi-wavelength simultaneous probe. This coupler device can be
19 used wherever it is required to split a single infrared beam into
20 two or more, using low-loss infrared fiber with a highly
21 adjustable numerical aperture.

22
23 ALTERNATIVES

Serial No.:

Inventors: David T. Schaafsma
Jasbinder S. Sanghera
Ishwar D. Aggarwal

Patent Application
Navy Case No. 78,344

1 An optical fiber coupler can be made from chalcogenide glass
2 simply by connecting two core-only fibers using heat shrink
3 material. However, such a device nearly eliminates the advantage
4 of these infrared fibers, since core-only fiber has very high
5 losses, and does not achieve a high coupling ratio
6 (experimentally, less than 6:1). It is also not amenable to
7 singlemode fiber.

8
9 The same effect can be achieved without using fiber and
10 resorting to free-space or bulk waveguide optics. This
11 technique, which is the current state of the art, suffers from
12 high scattering and/or injection losses, as well as problems with
13 atmospheric absorption of the infrared signal and does not lend
14 itself as easily to miniaturization or environmental ruggedness
15 and may not be as economically feasible as a fiber device.

16
17 Therefore, what has been described in preferred embodiments
18 of the invention is an infrared fiber optic coupler and a method
19 for making an infrared fiber optic coupler. The method comprises
20 the steps of: braiding first and second infrared transmitting
21 glass fibers to form first and second arms of the infrared fiber
22 optic coupler; inserting the braided first and second infrared
23 transmitting glass fibers through a furnace; securing the braided

Serial No.:

Inventors: David T. Schaafsma
Jasbinder S. Sanghera
Ishwar D. Aggarwal

Patent Application
Navy Case No. 78,344

1 glass fibers by two clamping mechanisms on first and second sides
2 of the furnace; purging the furnace of water vapor and oxygen
3 with a steady flow of inert gas through the furnace; allowing
4 infrared light pulses to pass through one of the first and second
5 arms of the coupler; detecting the infrared signals from the
6 first and second arms of the coupler in first and second infrared
7 detectors; comparing the detected signals to develop a coupling
8 ratio between the first and second arms of the coupler; turning
9 the furnace on to heat the first and second braided glass fibers
10 to the point where the glass fibers begin to darken in color;
11 translating the second clamping mechanism to produce a tautness
12 on the first and second braided glass fibers until the desired
13 coupling ratio has been achieved; turning the furnace off; and
14 maintaining tension on the first and second braided glass fibers
15 until the fibers cool to rigidity; and turning off the inert gas
16 flow.

17
18 It should therefore readily be understood that many
19 modifications and variations of the present invention are
20 possible within the purview of the claimed invention. It is
21 therefore to be understood that

22 the invention may be practiced otherwise than as
23 specifically described.

Serial No.:

Inventors: David T. Schaafsma
Jasbinder S. Sanghera
Ishwar D. Aggarwal

Patent Application
Navy Case No. 78,344

ABSTRACT

An infrared fiber optic coupler and a method for making an infrared fiber optic coupler are disclosed. The method comprises the steps of: braiding first and second infrared transmitting glass fibers to form first and second arms of the infrared fiber optic coupler; inserting the braided first and second infrared transmitting glass fibers through a furnace; securing the braided glass fibers by two clamping mechanisms on first and second sides of the furnace; purging the furnace of water vapor and oxygen with a steady flow of inert gas through the furnace; allowing infrared light to pass through one of the first and second arms of the coupler; detecting the infrared signals from the first and second arms of the coupler in first and second infrared detectors; comparing the detected signals to develop a coupling ratio between the first and second arms of the coupler; turning the furnace on to heat the first and second braided glass fibers to the point where the glass fibers begin to darken in color; translating the second clamping mechanism to produce a tautness on the first and second braided glass fibers until the desired coupling ratio has been achieved; turning the furnace off; maintaining tension on the first and second braided glass fibers until the fibers cool to rigidity; and turning off the gas flow.

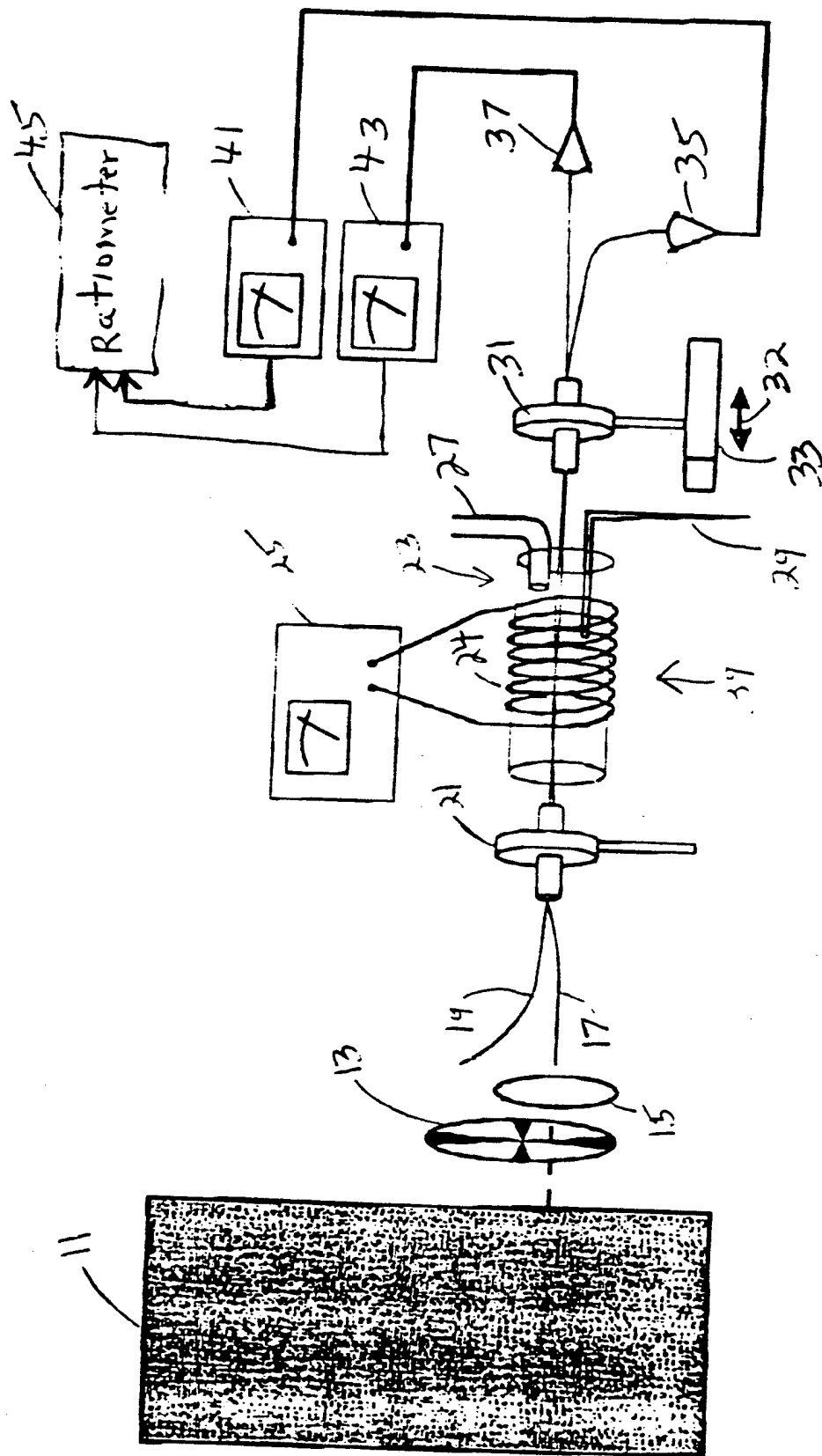


FIG. 1

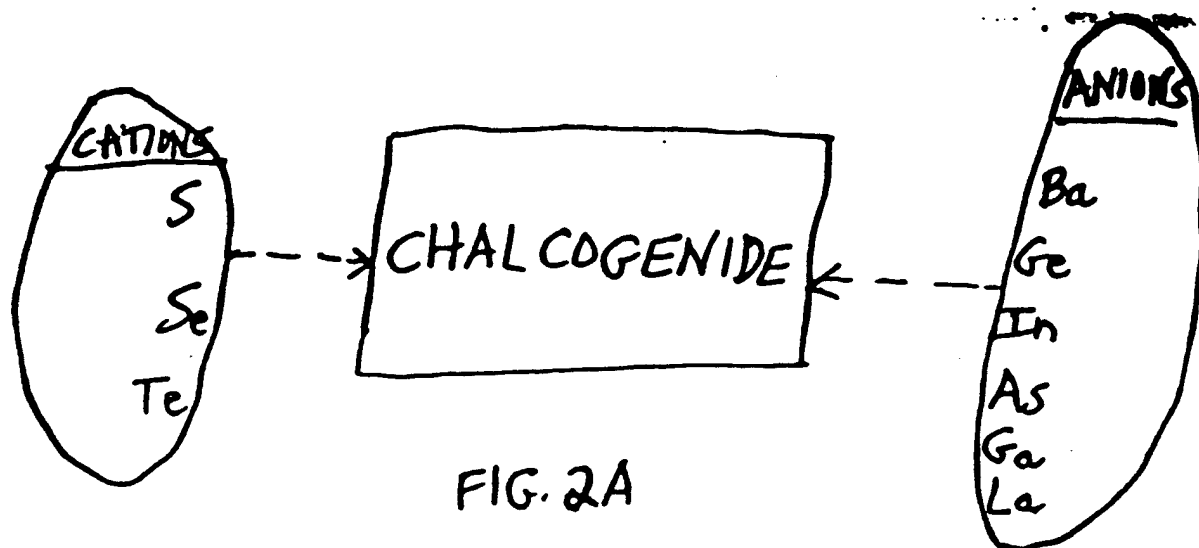


FIG. 2A

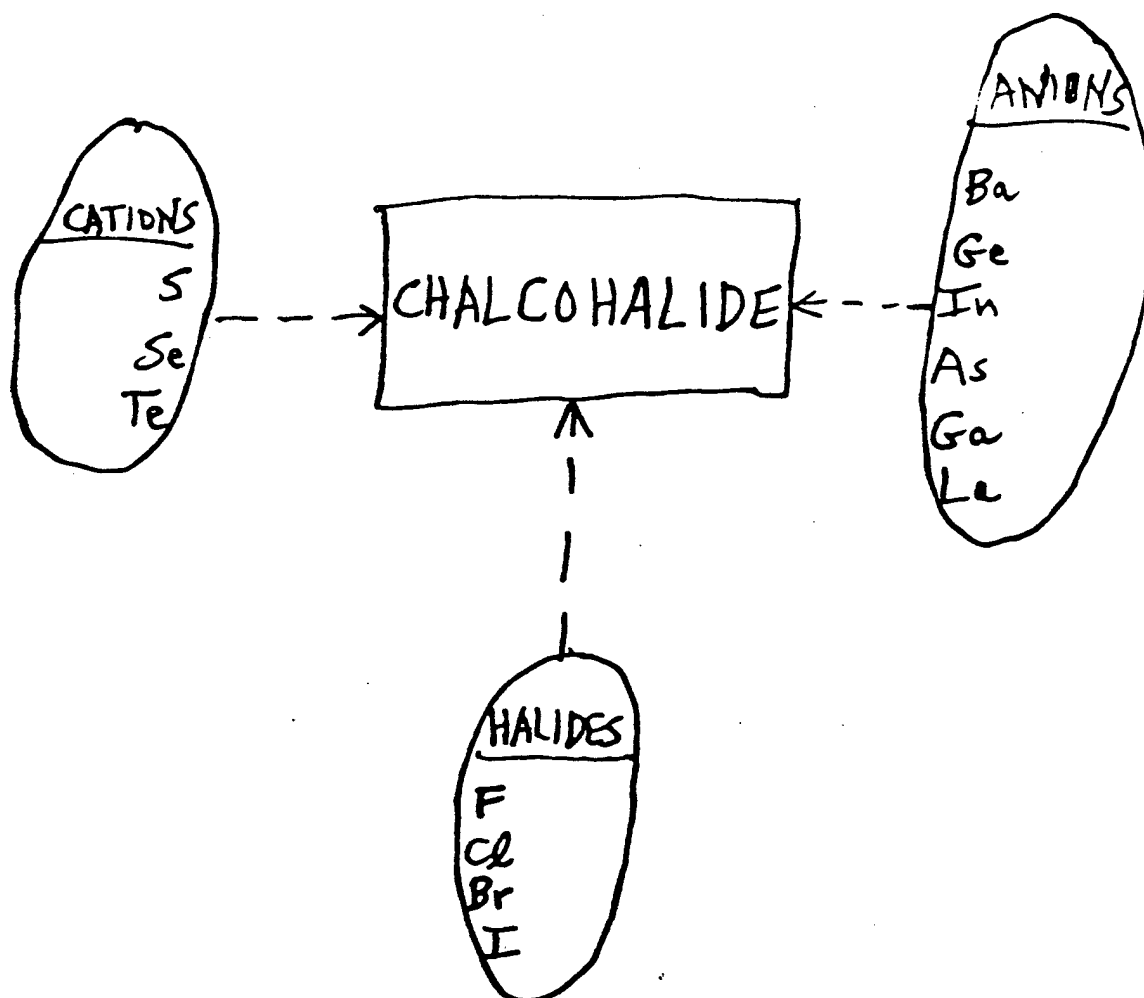


FIG 2B



FIG. 3A

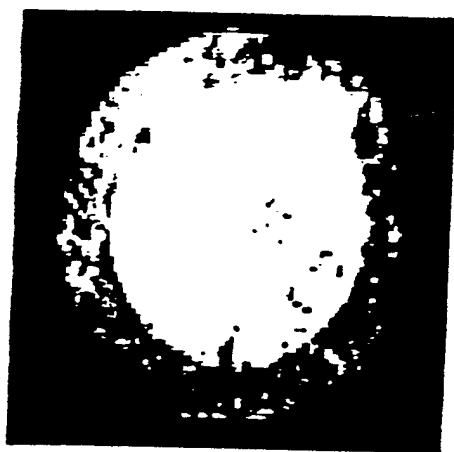


FIG. 3B

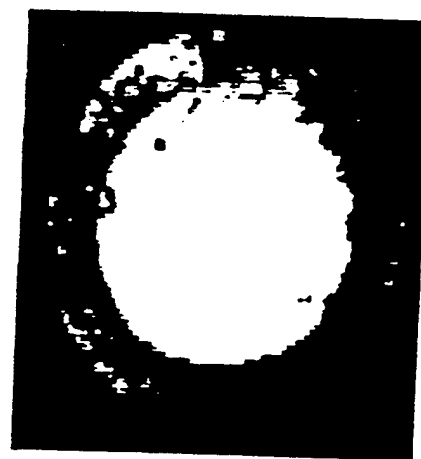


FIG 3C

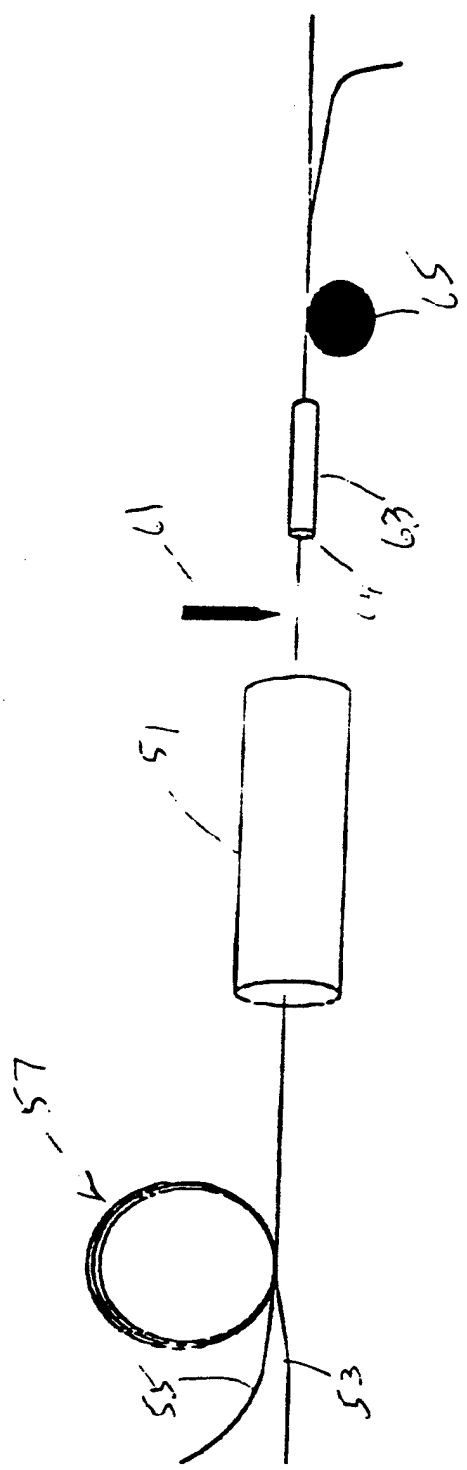


FIG. 4

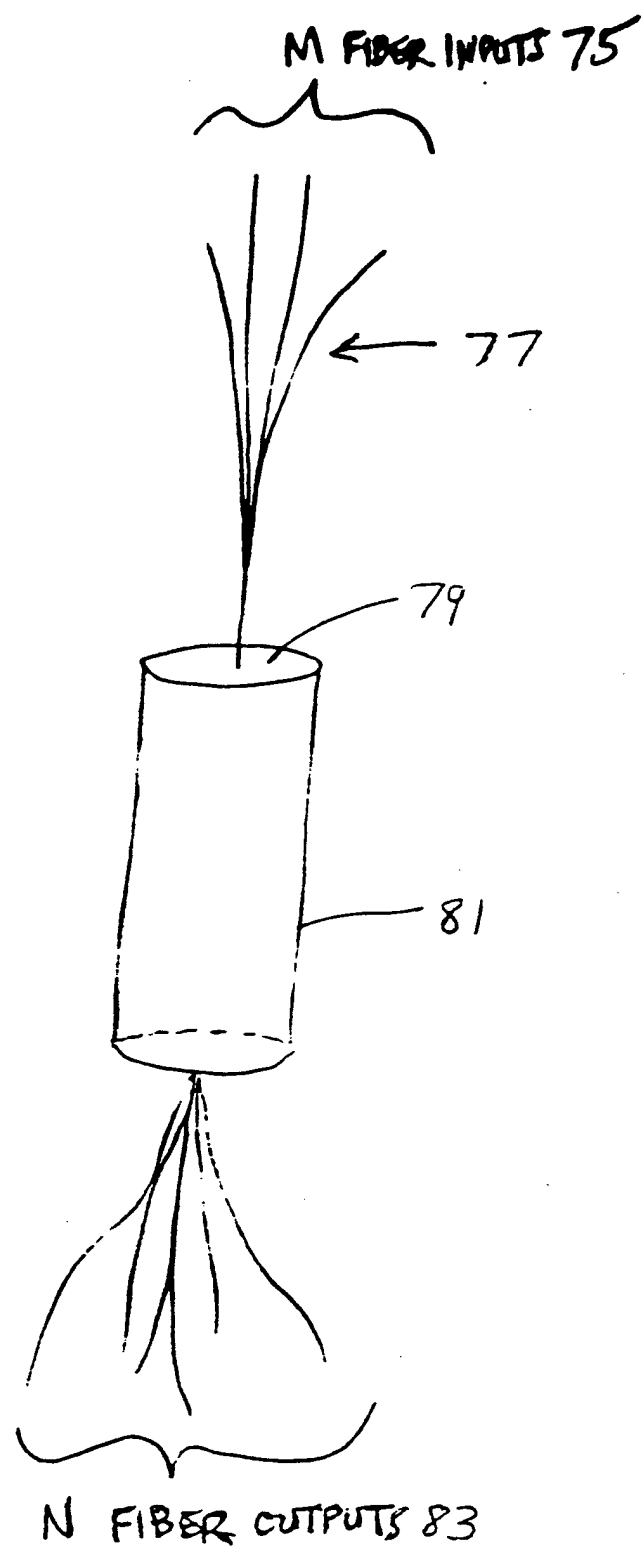


FIG. 5