and scope of the application will become apparent to those skilled in the art from this description and by practice of the apparatus, systems, and methods. The scope of the apparatus, systems, and methods is not intended to be limited to the particular forms disclosed and the application covers all modifications, equivalents, and alternatives falling within the spirit and scope of the apparatus, systems, and methods as defined by the claims.

Fluorescent lamp phosphors must meet a number of requirements, including: (1) strong absorption of the ultraviolet emission from mercury vapor (254 nm), (2) low absorption of the visible light emitted by the phosphors, (3) high quantum efficiency of conversion of the 254 nm light into visible light, (4) emission color stable, reproducible and meeting strict CIE coordinates to permit its use in a "triphosphor" blend by offering a spectrum that may be defined as "blue," "green," or "orange-red," (5) stability when exposed to high temperatures, (6) stability to water for storage and application onto the lamp envelope, (7) stability when exposed to high intensity ultraviolet light and mercury vapor. Requirements 1-4 provide the efficiency and quality of light needed, while 5 and 6 allow cost-effective processing, and 7 is needed for acceptable "lumen maintenance" or longevity of the phosphor under normal lamp operating conditions.

The inventors have developed a phosphor that does not utilize "critical rare earths." The inventor's phosphor includes aluminum nitride in the form of a powder which can be stored in water as a slurry, deposited on the inner surface of a lamp envelope and adhered to the envelope by heating in air. Aluminum nitride can form in several crystal structures, wurtzite, zincblende and rocksalt. The wurtzite form is most thermodynamically stable and only crystalline wurtzite (hexagonal phase) AlN and the variants based on the formula $Al_{(1-x)}M_xN$ are considered here (where M is a metal ion dopant). While undoped aluminum nitride emits blue light, it may additionally be doped with a variety of elements to promote visible luminescence, upon which the intrinsic defect-related blue emission is no longer observed, instead, emission from the dopant species dominates. In particular, doping with manganese results in strong orange-red emission from AlN. In one embodiment the inventors have developed a fluorescent lamp including a glass envelope; at least two electrodes connected to the glass envelope; mercury vapor and an inert gas within the glass envelope; and a phosphor blend on the inner surface of the glass envelope, wherein the phosphor blend includes aluminum nitride. Importantly, aluminum nitride has been found to exhibit excellent "lumen maintenance". To determine this feature of the AlN phosphor, the inventors tested the phosphor in a lamp under excitation conditions greater than normal and found no degradation in the phosphor's light output.

The inventors have synthesized manganese-doped AlN powder, and found it to offer high efficiency orange-red luminescence, when excited by the 254 nm mercury emission line. Its emission spectrum is very closely matched in CIE coordinates to that of the standard commercial orange-red phosphor, Y_2O_3:Eu. As such, AlN:Mn can function as a "drop-in" replacement for Y_2O_3:Eu. Fluorescent lamps may be manufactured that offer a range of CRI values and different qualities of white light, depending on the ratio of the blue, green and orange-red phosphors.

Many possible synthesis methods that may be used to form the AlN:Mn phosphor, among others, include:

(1) a solid-state reaction of AlN with a source of manganese in a high temperature nitrogen atmosphere, two examples of this are:

$$AlN(s)+xMnO \rightarrow AlN{:}xMn+(x/2)O_2(g) \quad (a)$$

$$AlN(s)+(x/3)Mn_3N_2 \rightarrow AlN{:}xMn \quad (b)$$

(2) carbothermal reaction, one example of this is:

$$Al_2O_3(s)+3C(s)+N_2(g)+xMn \rightarrow AlN{:}xMn+CO_2(g)$$

(3) direct nitridation of vapor or finely divided aluminum/manganese alloy, where the Mn content may range from 0.001% to 5%, the general reaction is:

$$2Al{:}Mn\ (s/l/g)+N_2(g) \rightarrow 2AlN{:}Mn(s)$$

Where "s" denotes solid, "1" is liquid, and "g" is gas or vapor.

Powder syntheses of AlN:Mn, as described above, typically yield particles with size between about 0.1 to 50 microns. Since fluorescent lighting functions best with 5-7 micron particles, additional steps such as ball milling may be required to reduce the average particle size.

The apparatus, systems, and methods are susceptible to modifications and alternative forms. Specific embodiments are shown by way of example. It is to be understood that the apparatus, systems, and methods are not limited to the particular forms disclosed. The apparatus, systems, and methods cover all modifications, equivalents, and alternatives falling within the spirit and scope of the application as defined by the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated into and constitute a part of the specification, illustrate specific embodiments of the apparatus, systems, and methods and, together with the general description given above, and the detailed description of the specific embodiments, serve to explain the principles of the apparatus, systems, and methods.

FIG. **1** is a flow chart illustrating a method of making one embodiment of a phosphor of the subject application.

FIG. **2** is a graph illustrating characteristics of one embodiment of a phosphor of the subject application.

FIG. **3** is a graph illustrating characteristics of one embodiment of a phosphor of the subject application.

FIG. **4** is an illustration of one embodiment of a fluorescent lamp of the subject application.

DETAILED DESCRIPTION OF SPECIFIC EMBODIMENTS

Referring to the drawings, to the following detailed description, and to incorporated materials, detailed information about the apparatus, systems, and methods is provided including the description of specific embodiments. The detailed description serves to explain the principles of the apparatus, systems, and methods. The apparatus, systems, and methods are susceptible to modifications and alternative forms. The application is not limited to the particular forms disclosed. The application covers all modifications, equivalents, and alternatives falling within the spirit and scope of the apparatus, systems, and methods as defined by the claims.

The market price for rare earth elements (the "critical rare earths") had risen appreciably several years ago, making the raw materials for phosphors expensive. The inventors have developed a phosphor that does not utilize "critical rare earths." The inventor's phosphor includes aluminum nitride in the form of a powder. In one embodiment the inventor's phosphor is deposited onto the surface of a fluorescent lamp envelope. In one embodiment the inventor's phosphor is phosphor doped to induce absorption at 254 nm and emission