constituting a sputtering target, the atom ratio of Ge/(In+Sn+Ge) is favorably 0.07 or more and 0.40 or less, and more favorably 0.10 or more and 0.25 or less. As a result, it is possible to obtain an amorphous oxide semiconductor thin film independent of the content of Sn. Further, by setting the Ge content to the range described above, it is possible to achieve both high mobility of 15 to 35 cm^2/Vs and carrier density of 10^{19} ($/cm^3$) order or less in the case where the atom ratio of In/(In+Sn+Ge) is 0.3 or more.

[0047] The sputtering target may further contain a first element (α) that is at least one element selected from the group consisting of Si (silicon), Ti (titanium), Mg (magnesium), Ca (calcium), Ba (barium), Zr (zirconium), Al (aluminum), W (tungsten), Ta (tantalum), Hf (hafnium), and B (boron). Each of these first elements (α) is an element serving as a carrier killer of the active layer, and contributes to the reduction of carrier density in the thin film, thereby making it possible to improve the reliability of a switching operation of the thin film transistor.

[0048] The amount of the first element (α) to be added is not particularly limited. For example, the atom ratio of α/(In+Sn+Ge+α) is 0.10 or less when the total of In, Sn, Ge, and α is represented by In+Sn+Ge+α. As a result, it is possible to reliably

controlled by pulverizing and classifying, by a roll mill, those obtained by compressing a dried body by a press. Meanwhile, in the case where the slurry is directly dried using a spray dryer or the like as a granulation method, the bulk density is controlled by the slurry concentration, the viscosity, the condition of the spray dryer, or the like.

[0084] (Molding step)

[0085] In the molding step, the granulated powder is molded into a predetermined shape (Step 104). Typically, the granulated powder is molded into a rectangular plate shape from which a desired long target is obtained. As the molding method, typically, a CIP method is employed. In addition thereto, a mold pressing method or the like may be employed.

[0086] The molding pressure is set to 100 MPa/cm^2 or more. In the case where the molding pressure is less than 100 MPa/cm^2, the molded body is fragile and difficult to handle, and the relative density of the sintered body tends to decrease. Meanwhile, by setting the molding pressure to 100 MPa/cm^2 or more, a sintered body having the relative density of 97% or more can be obtained.

[0087] The molding can be one of CIP and mold pressing as long as the pressure of 100 MPa/cm^2 or more can be achieved. When the area of a mold increases, the

germanium oxide of the raw material powders, and Part (b) of Fig. 14 shows the results in the case of using only germanium oxide having a hexagonal crystal as the raw material powder of germanium oxide of the raw material powders.

[0126] As shown in Parts (a) and (b) of Fig. 14, the particle diameter is smaller and the grindability is improved in the case of using only germanium oxide having a hexagonal crystal as the raw material powder of germanium oxide of the raw material powders as compared with the case of using a mixed powder of germanium oxide having a hexagonal crystal and germanium oxide having a tetragonal crystal.

[0127] Parts (a) and (b) of Fig. 15 each show an electronic microscope image of the polished surface of the sintered body. Part (a) of Fig. 15 shows the results in the case of using a mixed powder of germanium oxide having a hexagonal crystal and germanium oxide having a tetragonal crystal as the raw material powder of germanium oxide of the raw material powders, and Part (b) of Fig. 15 shows the results in the case of using only germanium oxide having a hexagonal crystal as the raw material powder of germanium oxide of the raw material powders. The firing conditions in Parts (a) and (b) of Fig. 15 are the same.

[0128] As shown in Parts (a) and (b) of Fig. 15, a sintered body having a smaller particle diameter and higher dispersibility of the raw material powder (Part (b) of Fig. 15) is obtained in the case of using only germanium oxide having a hexagonal crystal as the raw material powder of germanium oxide of the raw material powders as compared with the case of using a mixed powder of germanium oxide having a hexagonal crystal and germanium oxide having a tetragonal crystal (Part (a) of Fig. 15).

[0129] Fig. 16 is a schematic cross-sectional view showing a configuration of a thin film transistor in which a target according to this embodiment is used. In this embodiment, a so-called bottom gate type electric field effect transistor will be described as an example.

[0130] [Thin film transistor]

[0131] A thin film transistor 100 according to this embodiment includes a gate electrode 11, a gate insulating film 12, an active layer 13, a source electrode 14S, and a drain electrode 14D.

[0132] The gate electrode 11 is formed of a conductive film formed on the surface of a base material 10. The base material 10 is typically a transparent glass substrate. The gate electrode 11 typically includes a metal single-layer film or a metal

total amount of In, Sn, Ge, and Ti was In: 76 at%, Sn: 7 at%, Ge: 10 at%, and Ti: 7 at% was prepared on a glass substrate using a target obtained by adding Ti as the first element (α) to an In-Sn-Ge-O material. The obtained thin film was amorphous.

As a result of evaluating the electrical properties of the prepared oxide semiconductor thin film, the mobility was 15.0 cm^2/Vs and the carrier density was 7.9E+17 $(7.9\times10^{17})/cm^3$.

[0202] (Sample No. 9-4)

An In-Sn-Ge-Ti-O oxide semiconductor thin film in which the atom ratio of each of the elements in the total amount of In, Sn, Ge, and Ti was In: 71 at%, Sn: 7 at%, Ge: 10 at%, and Ti: 12 at% was prepared on a glass substrate using a target obtained by adding Ti as the first element (α) to an In-Sn-Ge-O material. The obtained thin film was amorphous.

As a result of evaluating the electrical properties of the prepared oxide semiconductor thin film, the mobility was 6.5 cm^2/Vs and the carrier density was 1.2E+17 $(1.2\times10^{17})/cm^3$.

[0203] (Sample No. 9-5)

An In-Sn-Ge-Ca-O oxide semiconductor thin film in which the atom ratio of each of the elements in the total amount of In, Sn, Ge, and Ca was In: 82 at%, Sn: 7 at%, Ge: 10 at%, and Ca: 1 at% was prepared on a

glass substrate using a target obtained by adding Ca as the first element (α) to an In-Sn-Ge-O material. The obtained thin film was amorphous.

As a result of evaluating the electrical properties of the prepared oxide semiconductor thin film, the mobility was 25.9 cm^2/Vs and the carrier density was 9.0E+18 $(9.0\times10^{18})/cm^3$.

[0204] (Sample No. 9-6)

An In-Sn-Ge-Ca-O oxide semiconductor thin film in which the atom ratio of each of the elements in the total amount of In, Sn, Ge, and Ca was In: 80 at%, Sn: 7 at%, Ge: 10 at%, and Ca: 3 at% was prepared on a glass substrate using a target obtained by adding Ca as the first element (α) to an In-Sn-Ge-O material. The obtained thin film was amorphous.

As a result of evaluating the electrical properties of the prepared oxide semiconductor thin film, the mobility was 20.5 cm^2/Vs and the carrier density was 3.4E+18 $(3.4\times10^{18})/cm^3$.

[0205] (Sample No. 9-7)

An In-Sn-Ge-Ca-O oxide semiconductor thin film in which the atom ratio of each of the elements in the total amount of In, Sn, Ge, and Ca was In: 78 at%, Sn: 7 at%, Ge: 10 at%, and Ca: 5 at% was prepared on a glass substrate using a target obtained by adding Ca as the first element (α) to an In-Sn-Ge-O material. The

obtained thin film was amorphous.

As a result of evaluating the electrical properties of the prepared oxide semiconductor thin film, the mobility was 18.9 cm^2/Vs and the carrier density was 1.9E+18 $(1.9\times10^{18})/cm^3$.

[0206] (Sample No. 9-8)

An In-Sn-Ge-Ca-O oxide semiconductor thin film in which the atom ratio of each of the elements in the total amount of In, Sn, Ge, and Ca was In: 71 at%, Sn: 7 at%, Ge: 10 at%, and Ca: 12 at% was prepared on a glass substrate using a target obtained by adding Ca as the first element (α) to an In-Sn-Ge-O material. The obtained thin film was amorphous.

As a result of evaluating the electrical properties of the prepared oxide semiconductor thin film, the mobility was 8.9 cm^2/Vs and the carrier density was 6.1E+17 $(6.1\times10^{17})/cm^3$.

[0207] (Sample No. 9-9)

An In-Sn-Ge-Ga-O oxide semiconductor thin film in which the atom ratio of each of the elements in the total amount of In, Sn, Ge, and Ga was In: 79.5 at%, Sn: 7 at%, Ge: 10 at%, and Ga: 3.5 at% was prepared on a glass substrate using a target obtained by adding Ga as the second element (β) to an In-Sn-Ge-O material. The obtained thin film was amorphous.

As a result of evaluating the electrical

properties of the prepared oxide semiconductor thin film, the mobility was 26.6 cm^2/Vs and the carrier density was 7.2E+18 $(7.2\times10^{18})/cm^3$.

[0208] (Sample No. 9-10)

An In-Sn-Ge-Ga-O oxide semiconductor thin film in which the atom ratio of each of the elements in the total amount of In, Sn, Ge, and Ga was In: 75.6 at%, Sn: 7 at%, Ge: 10 at%, and Ga: 7.4 at% was prepared on a glass substrate using a target obtained by adding Ga as the second element (β) to an In-Sn-Ge-O material. The obtained thin film was amorphous.

As a result of evaluating the electrical properties of the prepared oxide semiconductor thin film, the mobility was 22.4 cm^2/Vs and the carrier density was 3.6E+18 $(3.6\times10^{18})/cm^3$.

[0209] (Sample No. 9-11)

An In-Sn-Ge-Ga-O oxide semiconductor thin film in which the atom ratio of each of the elements in the total amount of In, Sn, Ge, and Ga was In: 69.7 at%, Sn: 7 at%, Ge: 10 at%, and Ga: 13.3 at% was prepared on a glass substrate using a target obtained by adding Ga as the second element (β) to an In-Sn-Ge-O material. The obtained thin film was amorphous.

As a result of evaluating the electrical properties of the prepared oxide semiconductor thin film, the mobility was 17.6 cm^2/Vs and the carrier

density was 2.4E+18 (2.4×10^{18})/cm^3.

[0210] (Sample No. 9-12)

An In-Sn-Ge-Ga-O oxide semiconductor thin film in which the atom ratio of each of the elements in the total amount of In, Sn, Ge, and Ga was In: 59 at%, Sn: 7 at%, Ge: 10 at%, and Ga: 24 at% was prepared on a glass substrate using a target obtained by adding Ga as the second element (β) to an In-Sn-Ge-O material. The obtained thin film was amorphous.

As a result of evaluating the electrical properties of the prepared oxide semiconductor thin film, the mobility was 10.2 cm^2/Vs and the carrier density was 1.0E+18 (1.0×10^{18})/cm^3.

[0211] The results of Experimental Example 8 are collectively shown in Table 9.

[0212] (Table 9)

Claims

[1] A sputtering target, comprising:

an oxide sintered body including indium, tin, and germanium, wherein

an atom ratio of germanium with respect to a total of indium, tin, and germanium is 0.07 or more and 0.40 or less, and

an atom ratio of tin with respect to the total of indium, tin, and germanium is 0.04 or more and 0.60 or less.

[2] The sputtering target according to claim 1, wherein

an atom ratio of indium with respect to the total of indium, tin, and germanium is 0.3 or more, and an atom ratio of germanium with respect to the total of indium, tin, and germanium is 0.10 or more and 0.25 or less.

[3] The sputtering target according to claim 1, wherein

the oxide sintered body further includes a first element that is at least one element selected from the group consisting of Si, Ti, Mg, Ca, Ba, Zr, Al, W, Ta, Hf, and B.

[4] The sputtering target according to claim 3, wherein

an atom ratio of the first element with respect to

a total of indium, tin, germanium, and the first element is 0.10 or less.

[5] The sputtering target according to any one of claims 1 to 4, wherein

the oxide sintered body further includes a second element that is at least one element selected from the group consisting of Sr, Ga, and Zn.

[6] The sputtering target according to claim 5, wherein

an atom ratio of the second element with respect to a total of indium, tin, germanium, and the second element is 0.25 or less, when the second element being β.

[7] The sputtering target according to claim 1, wherein

a relative density is 97% or more.

[8] The sputtering target according to claim 1, wherein

a specific resistance value is 0.1 mΩ·cm or more and 10 mΩ·cm or less.

[9] The sputtering target according to claim 1, wherein

a specific resistance value in a thickness direction falls within a range of 0.8 or more and 1.2 or less with respect to an average value of a bulk specific resistance value.

[10] The sputtering target according to claim 1, wherein

the oxide sintered body has at least one compound phase of an In-O phase, an In-Sn-O phase, and an In-Ge-O phase.

[11] A method of producing a sputtering target, comprising:

forming a molded body by mixing an indium oxide powder, a tin oxide powder, and a germanium oxide powder; and

producing a sputtering target including an oxide sintered body by sintering the molded body in an oxygen atmosphere of 1500°C or more and 1600°C or less.