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(54) Title: METHOD TO PRODUCE A STRUCTURED TRANSMISSIVE OPTICAL ELEMENT

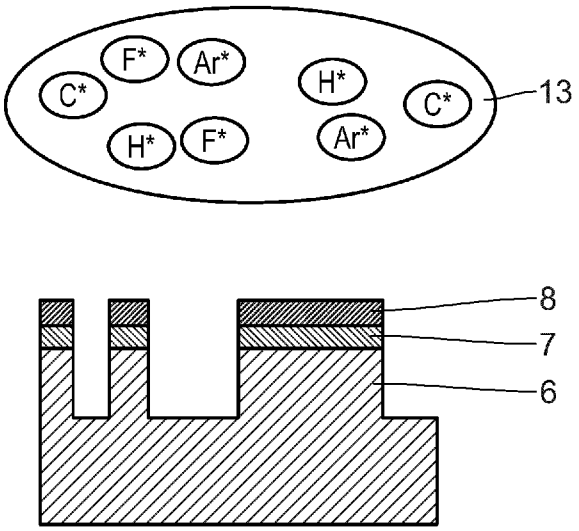


Fig. 6

(57) Abstract: To produce a structured transmissive optical element, a blank (6) of trans- missive optical material is provided and coated with a chrome layer (7) which itself is coated with a hard mask layer (8). The chrome and hard mask layer coated blank (6) then is coated with a resist which is exposed to a structurized beam. The resist is developed and portions of the developed resist are removed according to the structurized exposition. The hard mask layer (8) is etched via the removed portions of the resist with a hard mask etching process gas which is oxygen-free and chlorine-free. Via such etch- ing, portions of the hard mask layer (8) are removed at positions which cor- respond to the positions of the removed portions of the resist. In a compa- rable manner, the chrome layer (7) is etched via a chrome etching process gas containing oxygen and/or chlorine. Again in a comparable manner, the blank (6) is etched via removed portions of the chrome layer (7) with an oxygen-free and chlorine-free blank etching process gas (13) to remove portions of the blank (6) at positions which correspond to the positions of the removed portions of the chrome layer (7). In a last step, the remaining

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hard mask and chrome layer portions (8, 7) are removed from the etched blank (6). With such method, a structured transmissive optical element having a well-defined pattern structure with high definition and resolution can be produced.

Method to produce a structured transmissive optical element

The invention relates to a method to produce a structured transmissive optical element. Further, the invention relates to a structured transmissive optical element.

Methods to produce photo masks including layer coatings of different materials which are sequentially developed and etched are disclosed in US 6,472,107 B1, US 6,811,959 B2 and in US 6,989,219 B2.

It is an object of the present invention to provide a method to produce a structured transmissive optical element having a well-defined pattern structure with high definition and resolution.

This object is met by a production method according to claim 1.

According to the invention, three consecutive etching steps are part of the overall production method. The first and the third etching step is done with an oxygen-free and chlorine-free etching process gas. The intermediate etching step, i.e. etching of a chrome layer, is done with a chrome etching process gas containing oxygen and/or chlorine. This etching step sequence ensures that initial structures developed in the resist are not unwantedly affected during the etching step sequence, but are maintained with high accuracy to be transferred into the blank. This ensures that pattern structures of the produced transmissive optical element result with high accuracy and resolution. Quartz can be used as optical material of the blank. As structurized beam to expose the resist an electron beam can be used. Alternatively, a beam of exposure light can be used having a wavelength e.g. the EUV region between 5 nm and 30 nm or in the UV region, e.g. of 193 nm.

The method may be performed with a resist layer which is thinned down. A thickness of the resist layer may be in the range between 150 to 350 nm and may be around 150 nm, around 250 nm or around 350 nm. The thickness of the resist layer may be smaller than 150 nm. As a rule, the thickness of the resist layer is larger than 50 nm. The thickness of the chrome layer may be in the range between 40 nm and 50 nm. The thickness of the hard mask layer may be in the range between 25 nm and 35 nm.

In particular, it is avoided that unwantedly neighbouring layers are affected by the respectively used etching process gas.

The structure patterns may be structured in one dimension or may be alternatively structured in two lateral dimensions.

The resulting structured transmissive optical element may be transmissive across its whole lateral dimension, i.e. may not exhibit blocking mask structures.

Providing the hard mask layer from the same material as the blank according to claim 2 has proven to be particularly advantageous.

This holds in particular when using a hard mask layer made of SiO_2 according to claim 3.

Etching process gas variants according to claims 4 to 6 have proven efficiency during the production method. The hard mask etching process gas and the blank etching process gas may contain at least one of the following constituents: CF_4, C_4, F_8, C_4, F_6, CHF_3, SF_6, NF_3.

The blank etching process gas may be the same as the hard mask etching process gas. This diminishes the operating expense of the production method. Such use of the same process gas in particular is possible in case the hard mask layer is of the same material as the blank.

A structured transmissive optical element according to claim 7 exhibits well-defined structure patterns. l/h may be smaller than 1/10 (= 0.1). As a rule l/h is larger than 1/100 (=0.01).

The structure patterns may include dots and/or holes. The lateral dimension l refers to the diameter of a dot or to the thickness of a rib extending as a positive pattern structure beyond the base body. Further, the lateral dimension l may relate to the diameter or the gap width of a hole or "negative" rib structure.

The advantages of a structure transmissive optical element according to claim 8 correspond to those mentioned above with the production method. Such structured transmissive optical element may have an l/h ratio as discussed above.

Structured transmissive optical elements designed as a phase shift mask and/or as a diffractive optical element according to claims 9 and 10 have versatile applications.

In the following, exemplified embodiments of the invention are described with reference to the enclosed drawings, in which

Figs. 1 to 7 show in schematic sectional views, respectively, snap-shots of a method to produce a structured transmissive optical element in sequential order; and

Fig. 8 shows a schematic side view of a target pattern, i.e. the target structure of the transmissive optical element to be produced with the method.

Figs. 1 to 7 show as snap-shots sequential steps of a method to produce a structured transmissive optical element 1 (cf. Fig. 7) whose target pattern structure 2 is shown in the side view of Fig. 8. Examples for the transmissive optical element 1 to be produced are a phase shift mask which may be used as a reticle in a lithographic semiconductor production plant, in particular may be used in a projection exposure apparatus, or a diffractive optical element, e.g. a computer generated hologram, CGH.

The pattern structure 2 includes dots 3 and holes 4 as structure patterns. The dots 3 and the holes 4 have a lateral dimension l and have a height dimension h with respect to a base body 5 of the pattern structure 2. A relation between the lateral dimension l and the height dimension h, which is not shown in scale in Fig. 8 can be smaller than 1/10.

In the method to produce the structured transmissive optical element 1, initially a blank 6 of transmissive optical material is provided. The blank 6 can be made of quartz. The blank 6 then is coated with a chrome layer 7.

After that, the chrome layer coated blank is coated with a hard mask layer 8. The material of such hard mask layer 8 can be etched with an oxygen-free and chlorine-free hard mask etching process gas 9 (cf. Fig. 4). An ex-

ample for the material of the hard mask layer 8 is SiO_2. Another example for such material of the hard mask layer 8 is SiN.

The hard mask layer 8 can be made of the same material as the optical material of the blank 6.

After the hard mask layer coating, the chrome and hard mask layer coated blank is coated with a resist 10.

An intermediate result of the production method thus is a layer structure blank 6/chrome layer 7/hard mask layer 8/resist 10. Such layer structure is shown in Fig. 1.

Then, the resist 10 of such layer structure is exposed to a structurized beam 11. Such structurized beam may be given by an electron beam or alternatively by a light beam. The beam 11 is structurized such that portions of the resist 10 are exposed to the beam 11 while others are not. Beam exposure regions 10a on the resist 10 correspond with respect to the lateral position and extension, to the lateral position and extension of the holes 4 of the pattern structure 2 to be produced.

After the beam exposure which is shown in Fig. 2, the resist 10 is developed and portions of the developed resist 10 are removed according to the structurized exposition. The resulting intermediate product of the production method is shown in Fig. 3, showing the structured resist 10 with its removed portion. Those portions of the resist 10 are removed which previously were exposed by the structurized beam 11. Via the removed portions of the resist 10, the hard mask layer 8 is accessible.

Via the removed portions of the resist 10, the hard mask layer 8 then is etched with the hard mask etching process gas 9 as shown in Fig. 4. With such etching step, portions of the hard mask layer 8 are removed at positions which correspond to the positions of the removed portions of the resist 10.

The hard mask etching process gas 9 is a plasma containing argon ions, fluoride ions and hydrogen ions as visualized in Fig. 4.

After etching of the hard mask layer 8, via respectively removed portions of the hard mask layer 8, the chrome layer 7 now is accessible. Via the removed portions of the hard mask layer 8, the chrome layer 7 then is etched via a chrome etching process gas 12 as shown in Fig. 5.

The chrome etching process gas 12 is a plasma containing oxygen ions and chlorine ions as visualized in Fig. 5.

During such chrome layer etching step, portions of the chrome layer 7 are removed at positions which correspond to the positions of the removed portions of the hard mask layer 8.

After etching of the chrome layer 7, via respectively removed portions of the chrome layer 7, the blank 6 is accessible.

After etching of the chrome layer 7, via the removed portions of the chrome layer 7, etching of the blank 6 with an oxygen-free and chlorine-free blank etching process gas 13 is done to remove portions of the blank 6 at positions which correspond to the positions of the removed portions of the chrome layer 7.

This blank etching step is shown in Fig. 6.

The blank etching process gas 13 can have the same composition as the hard mask etching process gas 9 used in the step of Fig. 4. Alternatively, the blank etching process gas 13 may have a different composition than the hard mask etching process gas 9. In particular, the blank etching process gas 13 may include carbon ions.

After etching the blank 6 according to Fig. 6, the remaining hard mask and chrome layer portions are removed from the etched blank 6 as can be seen by comparing Figs. 6 and 7. The resulting structured transmissive optical element 1 has the target pattern structure 2 according to Fig. 8.

Since during the hard mask layer etching according to Fig. 4 the resist 10 is not affected by the hard mask etching process gas 9 and since further the hard mask structure is not affected during the chrome etching step according to Fig. 5 and since further the chrome layer structure is not affected during the blank etching step according to Fig. 6, the resulting pattern structure 2 in the mask blank 6 well approximates the target pattern structure 2.

Patent claims

1. Method to produce a structured transmissive optical element (1) with the following steps:

- providing a blank (6) of transmissive optical material,
- coating the blank (6) with a chrome layer (7),
- coating the chrome layer (7) coated blank (6) with a hard mask layer (8) which can be etched with an oxygen-free and chlorine-free hard mask etching process gas (9),
- coating the chrome and hard mask layer coated blank (6) with a resist (10),
- exposing the resist (10) to a structurized beam (11),
- developing the resist (10) and removed portions of the developed resist (10) according to the structurized exposition,
- etchging the hard mask layer (8) via the removed portions of the resist (10) with the hard mask etching process gas (9) to remove portions of the hard mask layer (8) at positions which correspond to the positions of the removed portions of the resist (10),
- etchging the chrome layer (7) via removed portions of the hard mask layer (8) with a chrome etching process gas (12) containing oxygen and/or chlorine to remove portions of the chrome layer (7) at positions which correspond to the positions of the removed portions of the hard mask layer (8),
- etching the blank (6) via removed portions of the chrome layer (7) with an oxygen-free and chlorine-free blank etching process gas (13) to remove portions of the blank (6) at positions which correspond to the positions of the removed portions of the chrome layer (7),

- removing the remaining hard mask and chrome layer portions (8, 7) from the etched blank (6).

2. Method according to claim 1, wherein the hard mask layer (8) is made of the same material as the optical material of the blank (6).

3. Method according to claim 1 or 2, wherein the hard mask layer (8) is made of SiO_2.

4. Method according to one of claims 1 to 3, wherein as hard mask etching process gas (9) a plasma is used containing at least one of the following ions: argon, fluoride, hydrogen.

5. Method according to one of claims 1 to 4, wherein as chrome etching process gas (12) a plasma is used containing at least one of the following ions: oxygen, chlorine.

6. Method according to one of claims 1 to 5, wherein as blank etching process gas (13) a plasma is used containing at least one of the following ions: argon, fluoride, hydrogen, carbon.

7. Structured transmissive optical element (1) having structure patterns (3, 4) extending beyond a base body (5) with a lateral dimension l and a height dimension h, wherein l/h is smaller than 1/3 (= 0.33).

8. Structured transmissive optical element (1) produced with a method according to one of claims 1 to 6.

9. Structured transmissive optical element (1) according to claims 7 or 8, being designed as a phase shift mask.

10. Structured transmissive optical element (1) according to claims 7 or 8, being designed as a diffractive optical element.

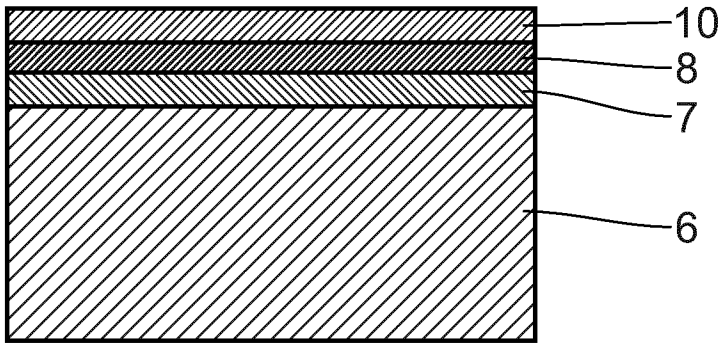


Fig. 1

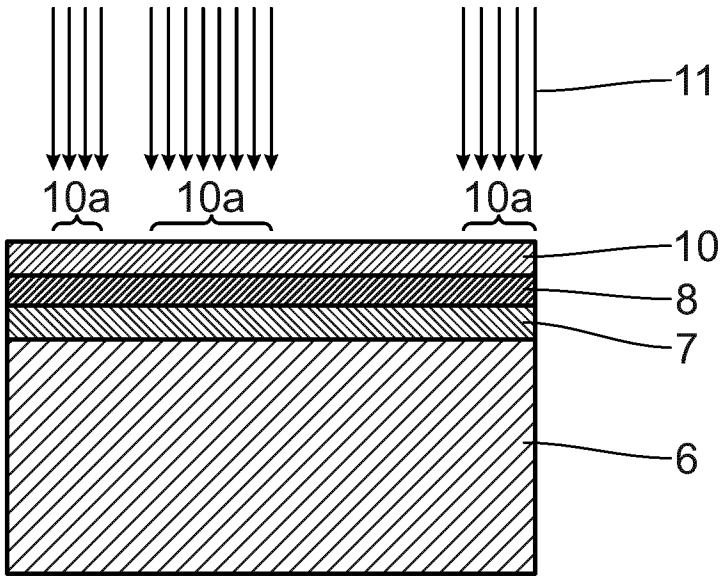


Fig. 2

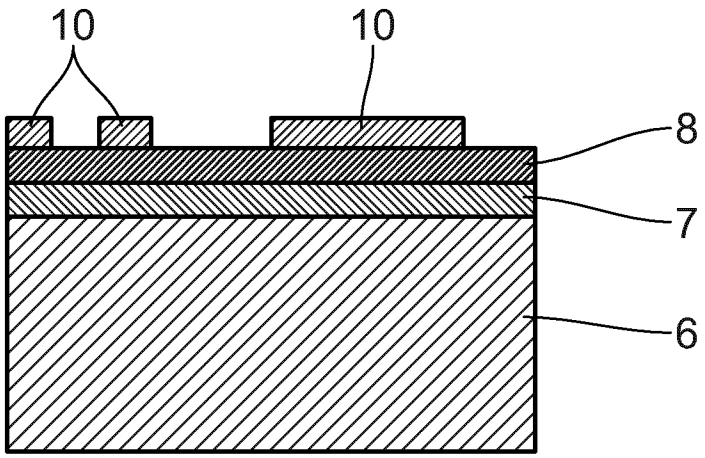


Fig. 3

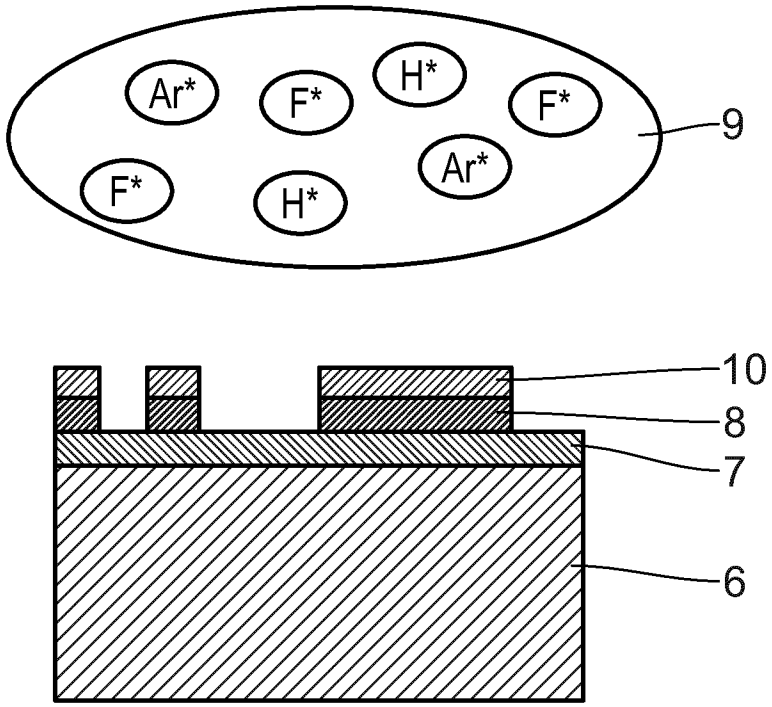


Fig. 4

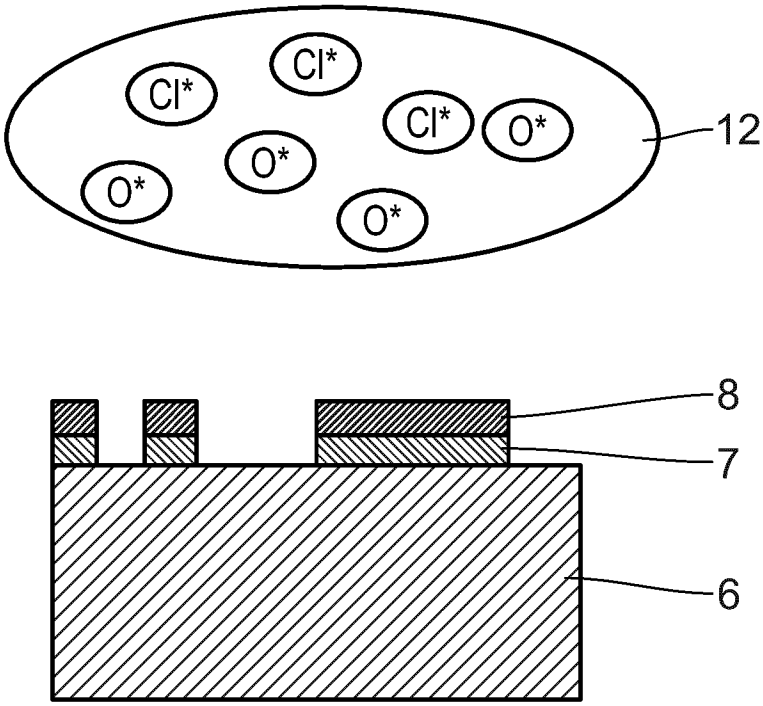


Fig. 5

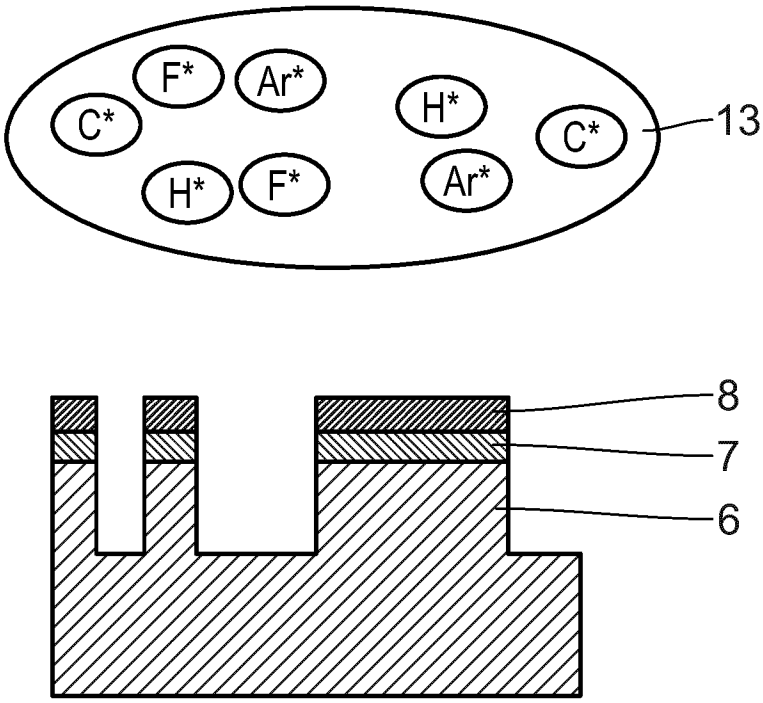


Fig. 6

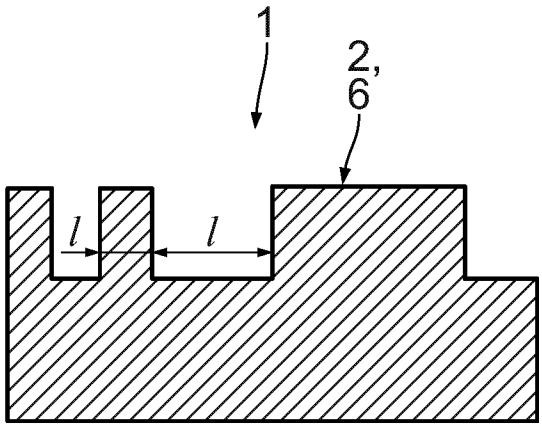


Fig. 7

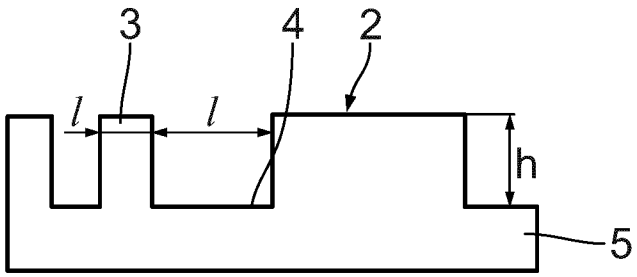


Fig. 8

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2020/077217

A. CLASSIFICATION OF SUBJECT MATTER
INV. G03F1/34 G02B5/18
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G03F G02B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2011/250529 A1 (NOZAWA OSAMU [JP]) 13 October 2011 (2011-10-13)	1,7
Y	paragraphs [0021], [0027] - [0029], [0054], [0066], [0162], [0163], [0172] - [0191]; figures 4A-4I	1-6,8-10
X	US 2010/173234 A1 (OKUBO YASUSHI [JP] ET AL) 8 July 2010 (2010-07-08)	7
Y	paragraphs [0014], [0026], [0049], [0054], [0153] - [0160], [0166], [0167], [0168]	1-6,8-10

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

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Date of the actual completion of the international search	Date of mailing of the international search report
15 June 2021	25/06/2021

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
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