



(51) International Patent Classification:

H01L 21/02 (2006.01) C23C 16/26 (2006.01)
H01L 21/033 (2006.01) C23C 16/511 (2006.01)

(21) International Application Number:

PCT/US2023/062534

(22) International Filing Date:

14 February 2023 (14.02.2023)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

17/671,938 15 February 2022 (15.02.2022) US

(71) Applicants: **APPLIED MATERIALS, INC.** [US/US];

3050 Bowers Avenue, Santa Clara, California 95054 (US).

NATIONAL UNIVERSITY OF SINGAPORE [SG/SG];

21 Lower Kent Ridge Road, Singapore 119077 (SG).

(72) Inventors: **SAHMUGANATHAN, Vicknesh**; Applied

Materials Singapore Technology Pte Ltd, 10 Science

Park Road, #02-03, The Alpha Science Park II,

Singapore 117684 (SG). **VENKATASUBRAMANIAN,**

Eswaranand; 3050 Bowers Avenue, Santa Clara, Califor-

nia 95054 (US). **GU, Jiteng**; National University of Singa-

pore, 21 Lower Kent Ridge Road, Singapore 119077 (SG).

LOH, Kian Ping; National University of Singapore, 21
Lower Kent Ridge Road, Singapore 119077 (SG). **MAL-**
LICK, Abhijit Basu; 3050 Bowers Avenue, Santa Clara,
California 95054 (US). **SUDIJONO, John**; Applied Mate-
rials Singapore Technology Pte Ltd, 10 Science Park Road,
#02-03, The Alpha Science Park II, Singapore 117684 (SG).

(74) Agent: **BLANKMAN, Jeffrey I.**; SERVILLA WHITNEY

LLC, 33 Wood Avenue South, Suite 830, Iselin, New Jersey
08830 (US).

(81) Designated States (*unless otherwise indicated, for every*

kind of national protection available): AE, AG, AL, AM,
AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ,
CA, CH, CL, CN, CO, CR, CU, CV, CZ, DE, DJ, DK, DM,
DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT,
HN, HR, HU, ID, IL, IN, IQ, IR, IS, IT, JM, JO, JP, KE,
KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU,
LY, MA, MD, MG, MK, MN, MW, MX, MY, MZ, NA, NG,
NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS,
RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH,
TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS,
ZA, ZM, ZW.

(84) Designated States (*unless otherwise indicated, for every*

kind of regional protection available): ARIPO (BW, CV,
GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ,

(54) Title: METHODS TO REDUCE UNCD FILM ROUGHNESS

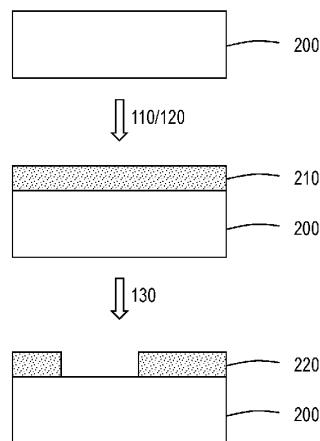


FIG. 2

(57) Abstract: Hard masks and methods of forming hard masks are described. The hard mask has an average roughness less than 10 nm and a modulus greater than or equal to 400 GPa. The method comprises exposing a substrate to a deposition gas comprising a dopant gas or a precursor (solid (e.g. Alkylborane compounds) or liquid (e.g. Borazine)), a carbon gas and argon at a temperature less than or equal to 550 C, and igniting a plasma from the deposition gas to form an ultrananocrystalline diamond film having an average roughness less than 10 nm and a modulus greater than or equal to 400 GPa.

TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, ME, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

- *with international search report (Art. 21(3))*
- *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*