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United States Patent [19]

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Brueck et al.

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[54] **METHOD AND APPARATUS FOR EXTENDING SPATIAL FREQUENCIES IN PHOTOLITHOGRAPHY IMAGES**

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[*] Notice: This patent is subject to a terminal disclaimer.

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[22] Filed: **Sep. 17, 1997**

[51] Int. Cl.⁷ **G03C 5/00**

[52] U.S. Cl. **430/316; 430/312; 430/323; 430/394**

[58] Field of Search **430/396, 397, 430/313, 312, 314, 316, 322, 323, 394**

[56] **References Cited**

U.S. PATENT DOCUMENTS

4,859,548	8/1989	Heise et al.	430/1
5,116,718	5/1992	Dalton et al.	430/327
5,216,257	6/1993	Brueck et al.	250/548
5,343,292	8/1994	Brueck et al.	356/363
5,415,835	5/1995	Brueck et al.	430/311
5,486,449	1/1996	Hosono et al.	430/328
5,705,321	1/1998	Brueck et al.	430/316
5,759,744	6/1998	Brueck et al.	430/312
5,790,254	8/1998	Ausschnitt	356/372
5,801,075	9/1998	Gardner et al.	438/197

OTHER PUBLICATIONS

D. H. Ziger and C. A. Mack "Generalized Approach toward Modeling Resist Performance," *AICHE Jour.* 37, 1863-1874 (1991).

W. D. Hinsberg, S.A. MacDonald, L. A. Pederson, and C. G. Willson "A Lithographic Analog of Color Photography: Self-Aligning Photolithography Using a Resist with Wavelength-Dependent Tone," *Jour. Imaging Sci.* 33, 129-135 (1989).

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Assistant Examiner—Jill N. Holloman

Attorney, Agent, or Firm—Snell & Wilmer, L.L.P.

[57] **ABSTRACT**

The present invention extends the available spatial frequency content of an image through the use of a method and apparatus for combining nonlinear functions of intensity to form three dimensional patterns with spatial frequencies that are not present in either of the individual exposures and that are beyond $2/\lambda$ in all three spatial directions. The resulting pattern has spatial frequency content beyond the limits set by optical propagation of spatial frequencies limited to $2/\lambda$ (e.g. pitch reduction from $\sim\lambda/2$ to at least $\sim\lambda/4$). The extension of spatial frequencies preferably extends the use of currently existing photolithography capabilities, thereby resulting in a significant economic impact. Multiplying the spatial frequency of lithographically defined structures suitably allows for substantial improvements in, inter alia, crystal growth, quantum structure growth and fabrication, flux pinning sites for high- T_c superconductors, form birefringent materials, reflective optical coatings, photonic bandgap, electronics, optical/magnetic storage media, arrays of field emitters, DRAM (Dynamic Random Access Memory) capacitors and in other applications requiring large areas of nm-scale features.

32 Claims, 19 Drawing Sheets

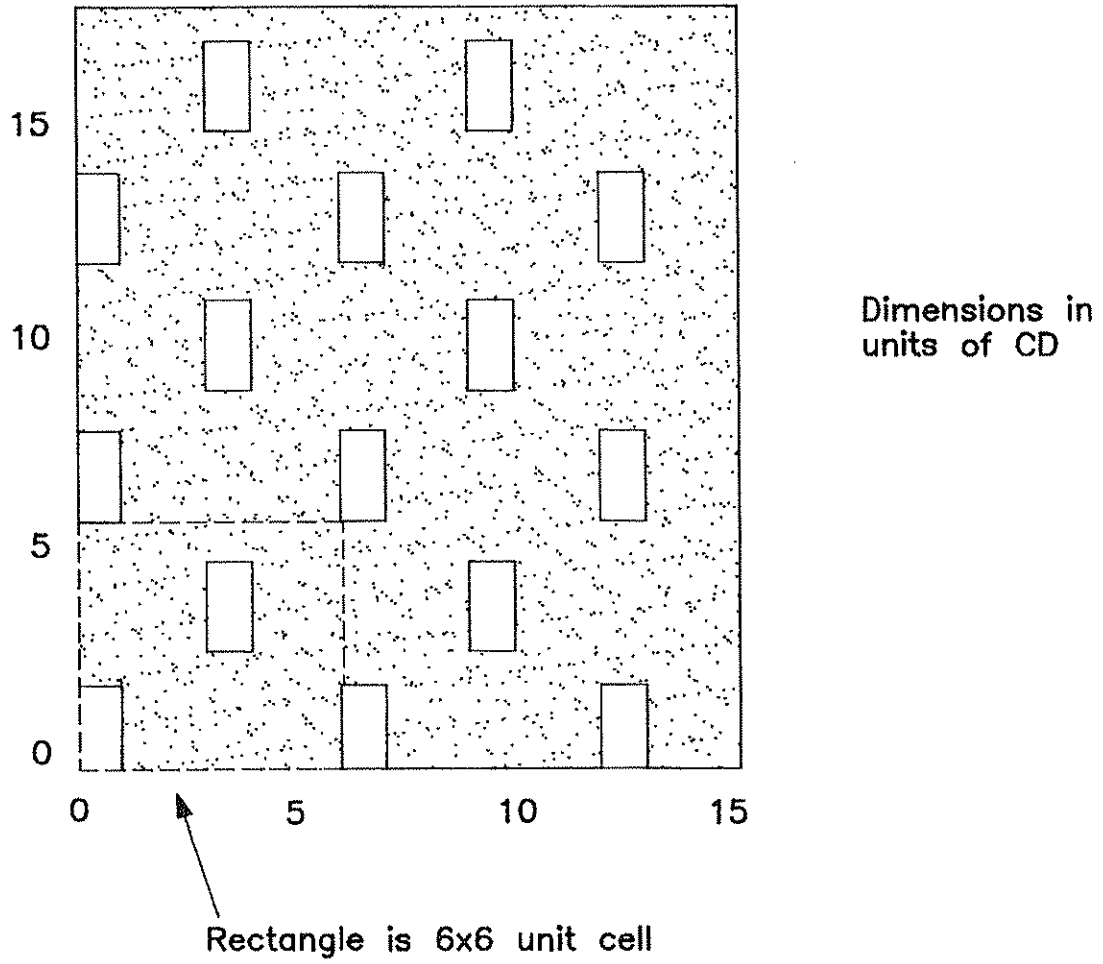


FIG. 1

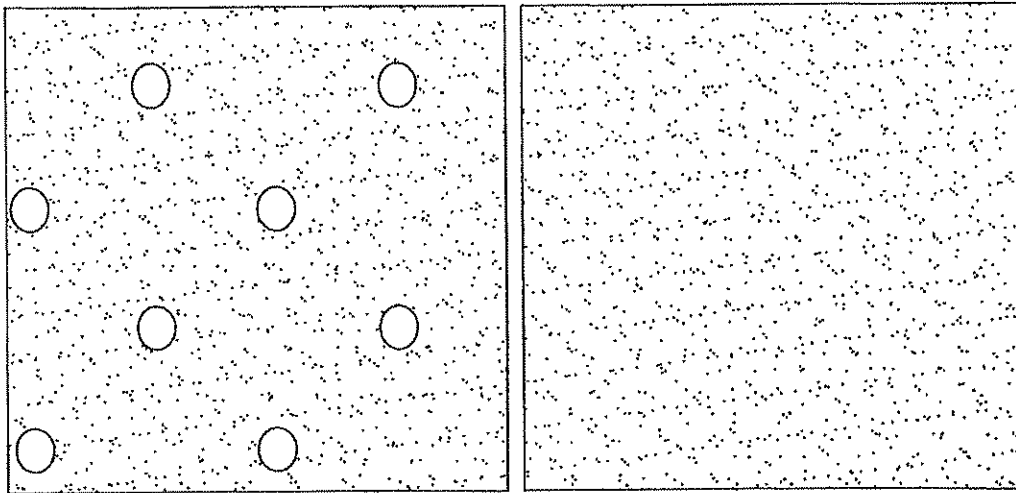


FIG. 2A

FIG. 2B

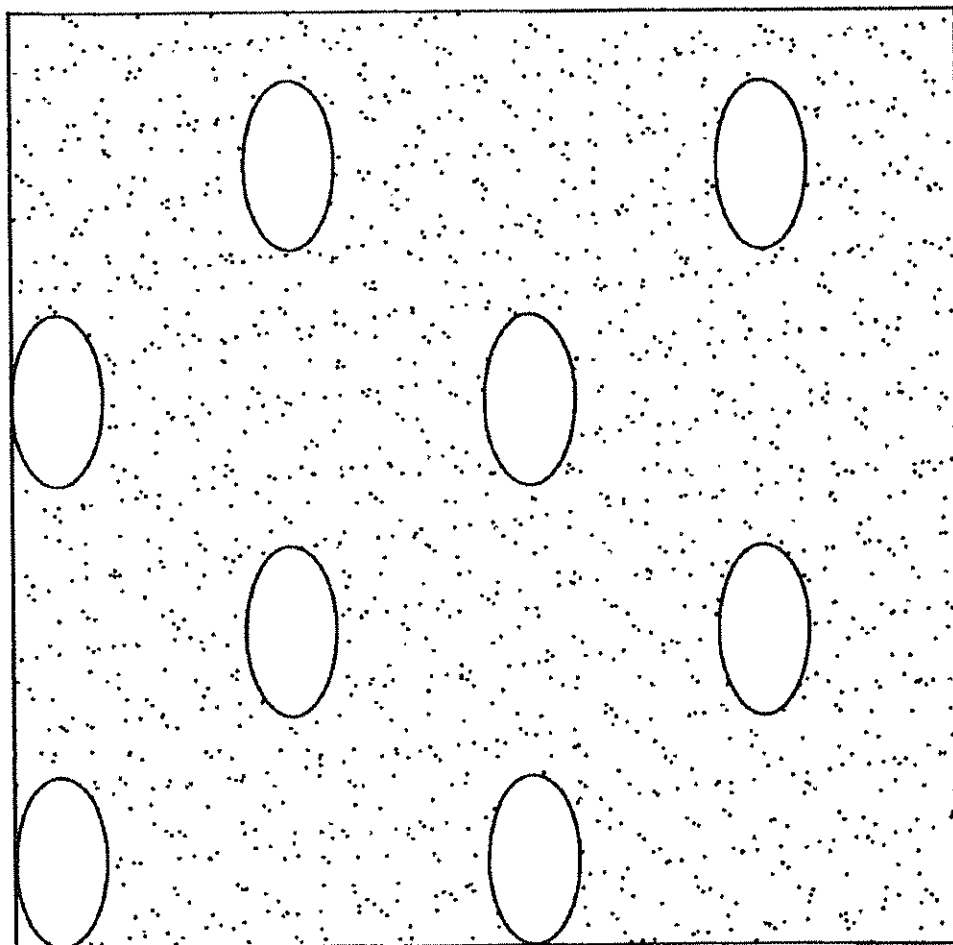


FIG. 3

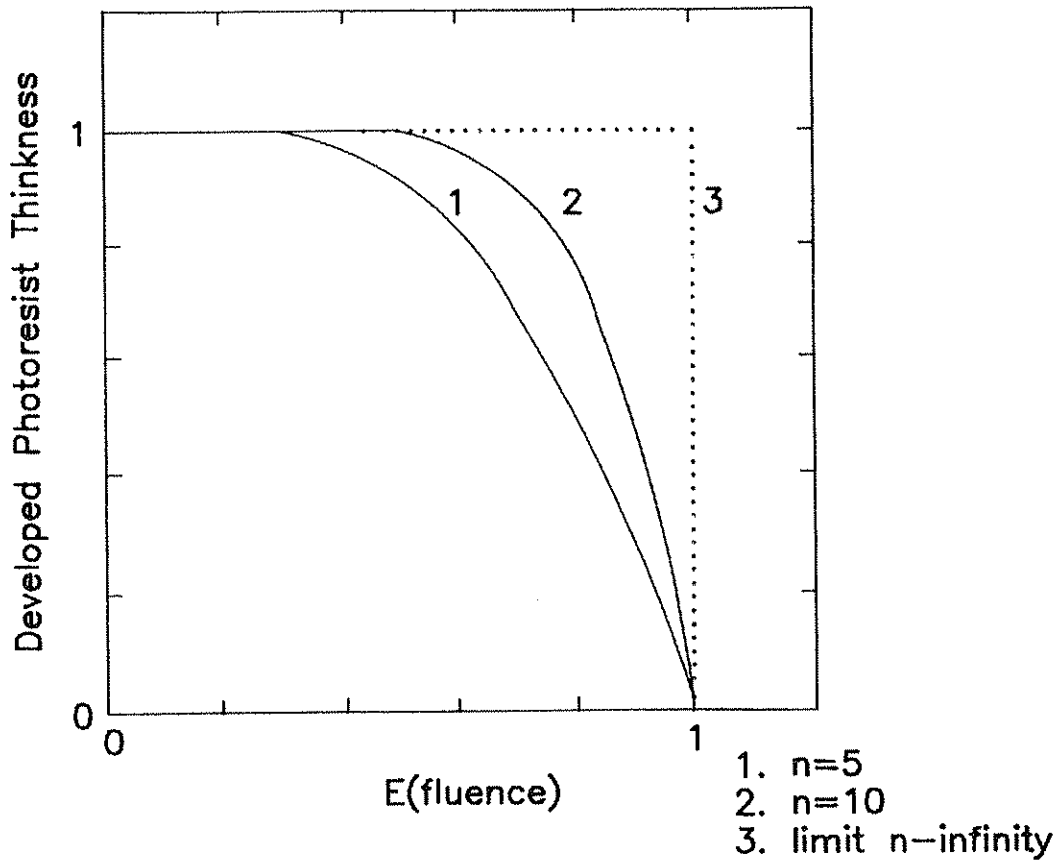


FIG. 4

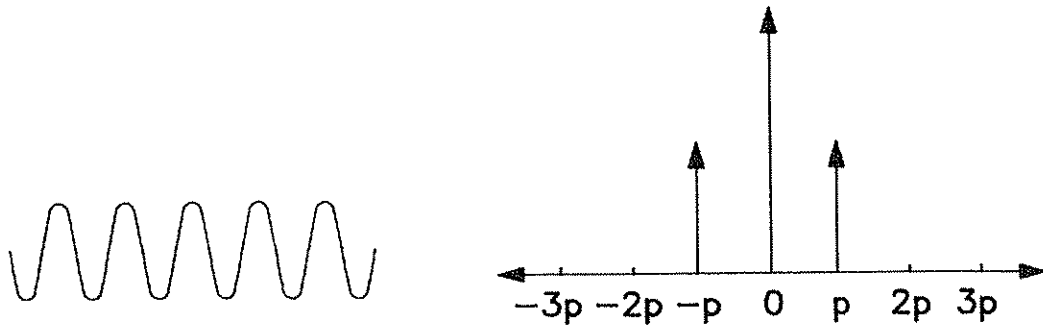


FIG. 5A

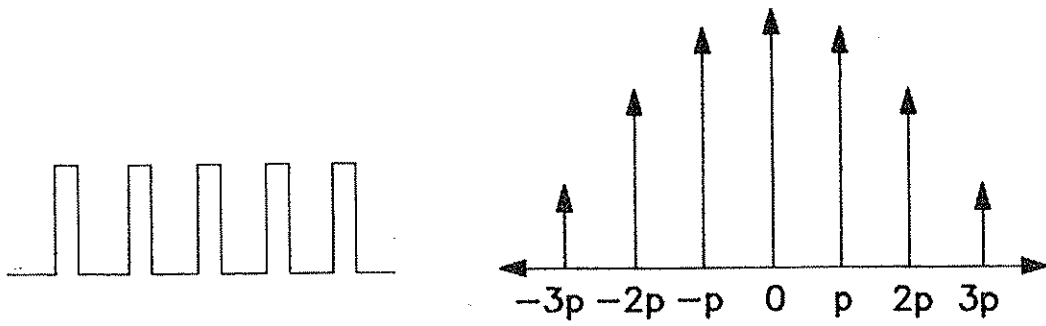


FIG. 5B

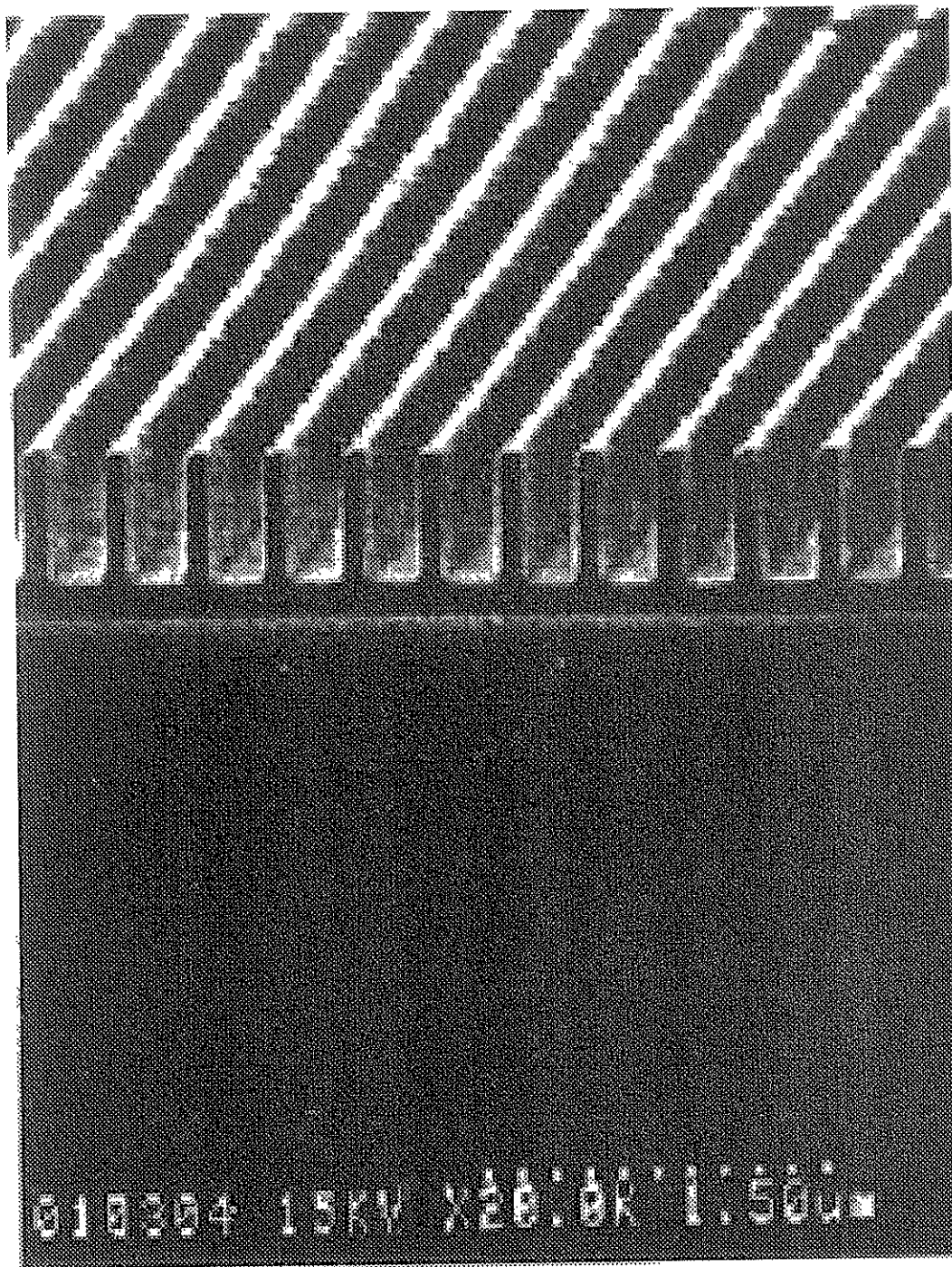


FIG. 5C

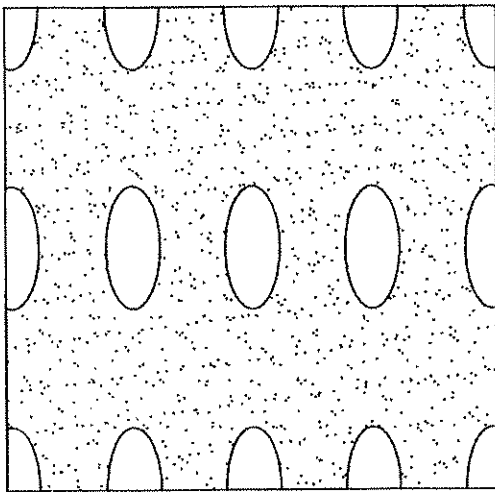


FIG. 6A

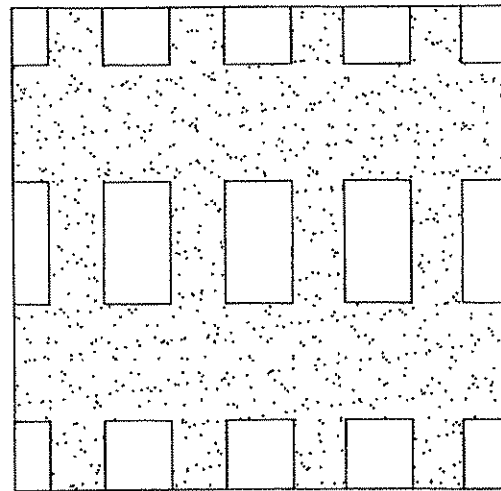


FIG. 6B

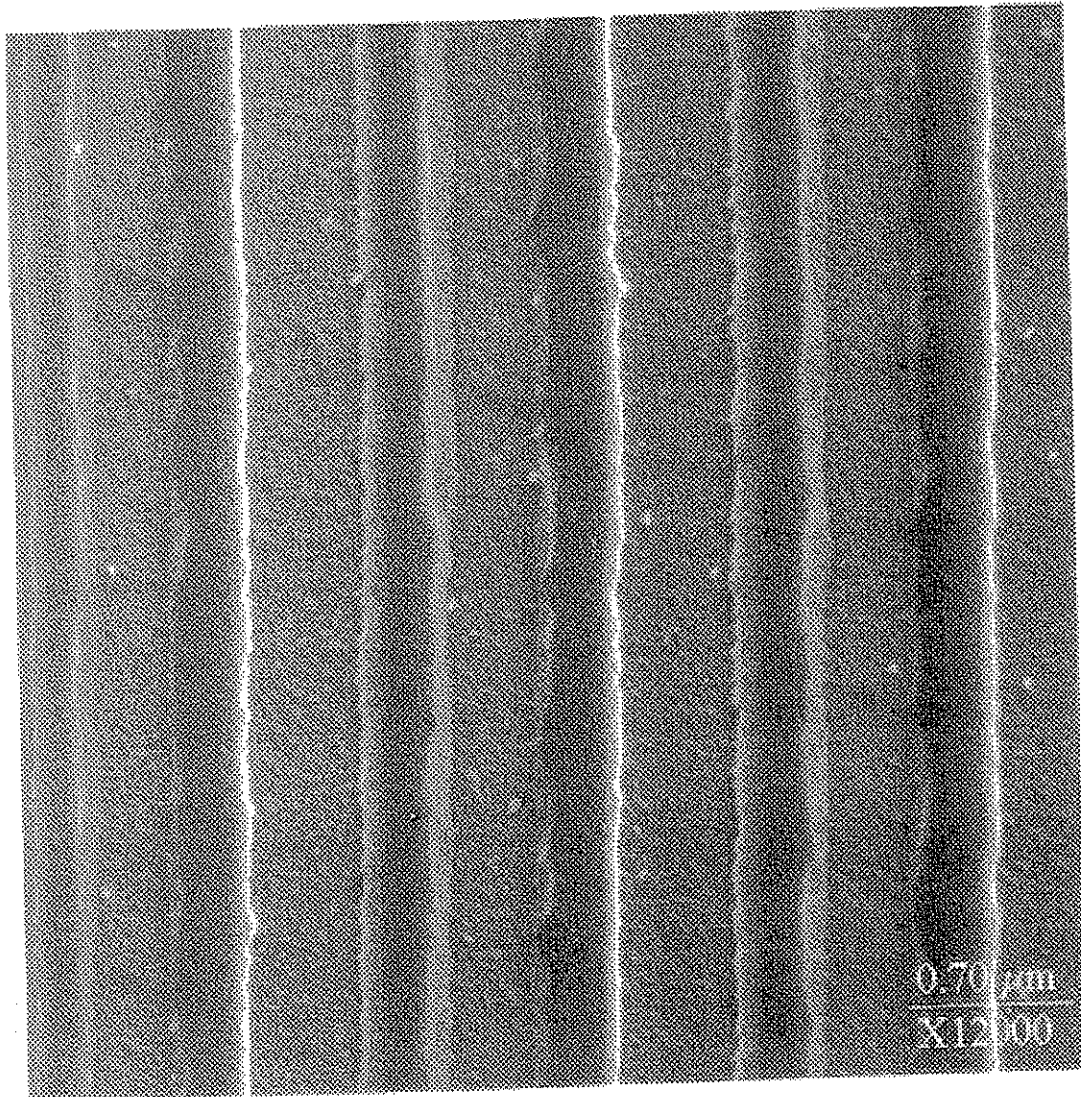


FIG. 7A

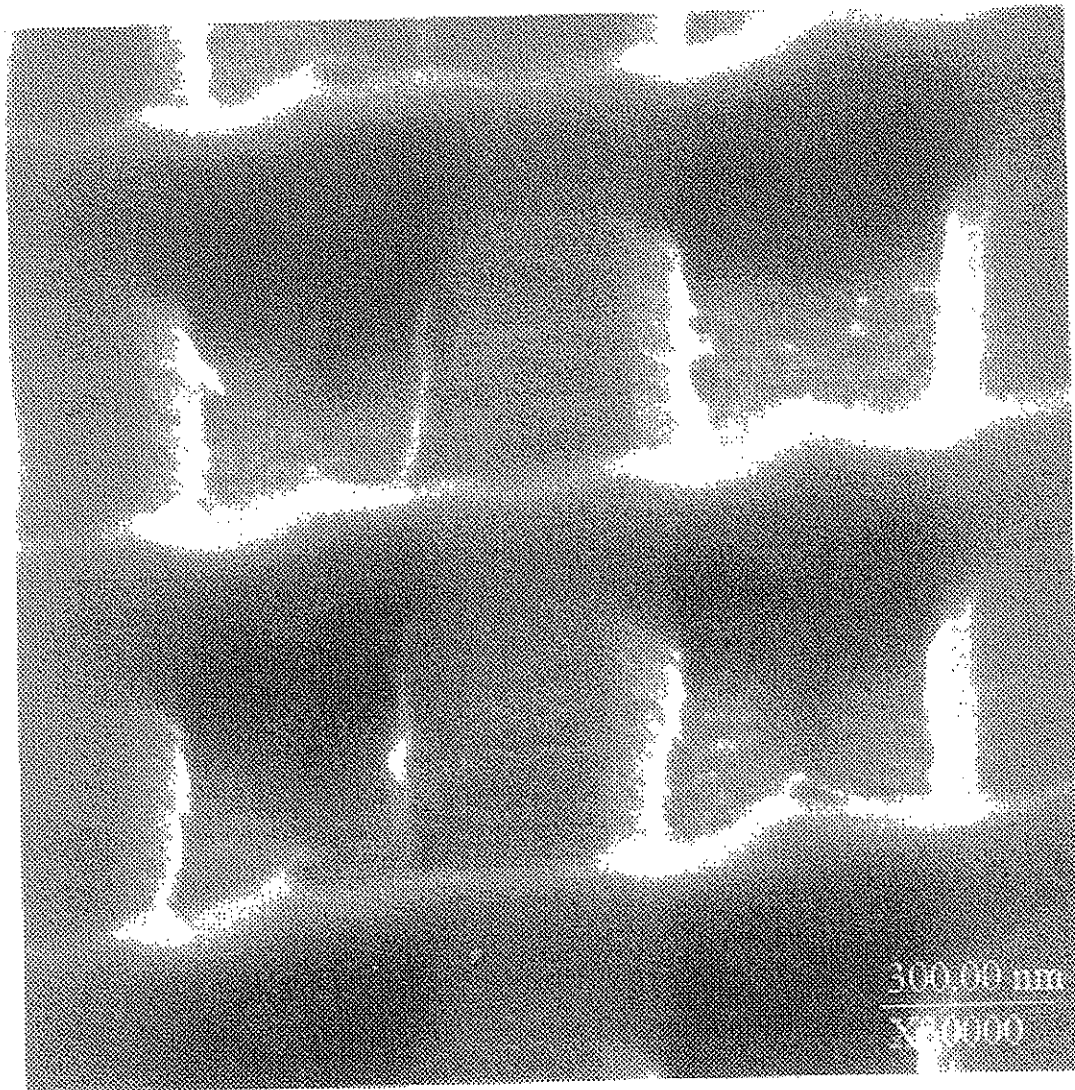


FIG. 7B

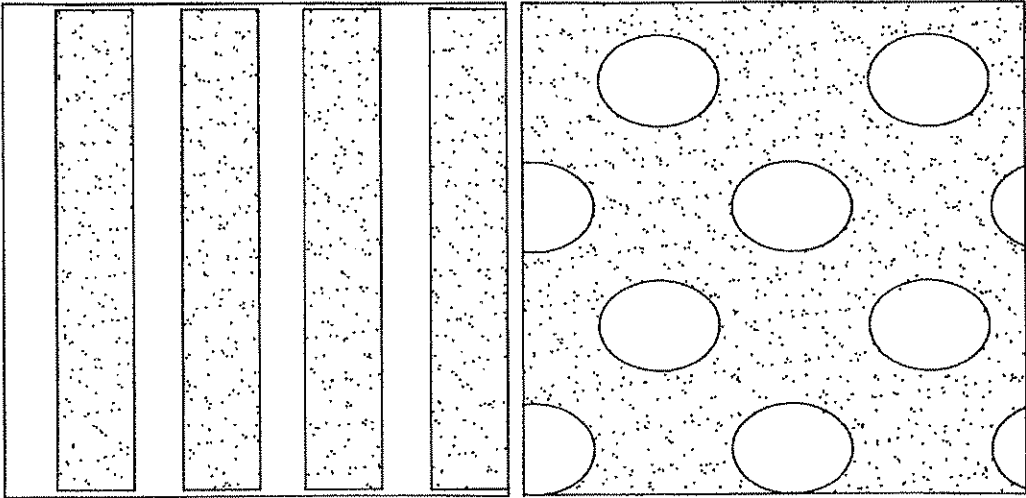


FIG. 8A

FIG. 8B

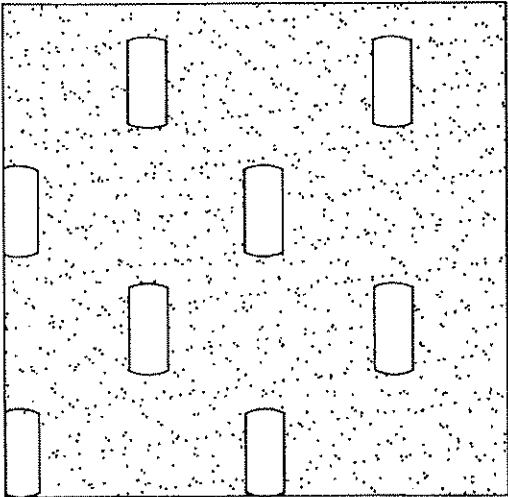


FIG. 8C

FIG. 9A

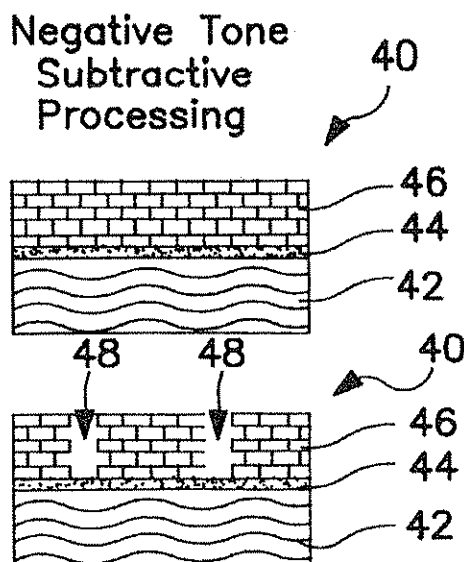


FIG. 9B

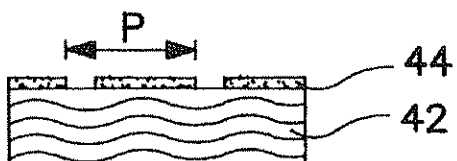


FIG. 9C

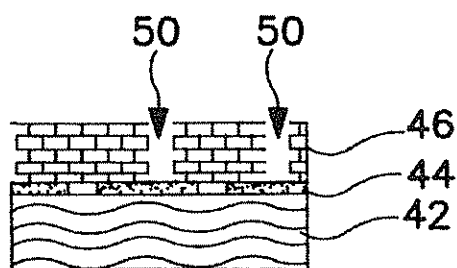


FIG. 9D

FIG. 9E

Positive Tone
Additive/Subtractive
Processing 60

FIG. 10A

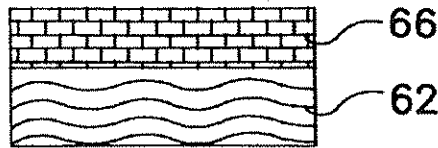


FIG. 10B

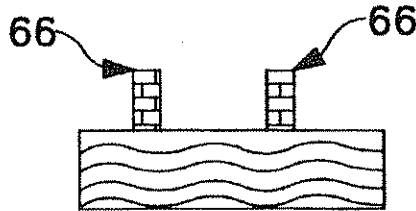


FIG. 10C

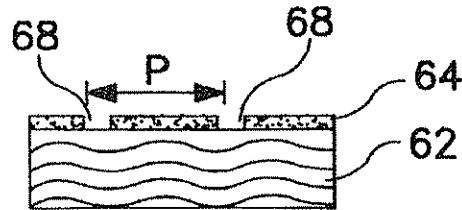


FIG. 10D

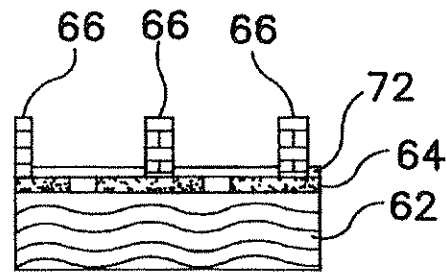


FIG. 10E

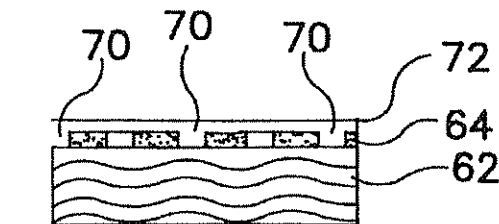
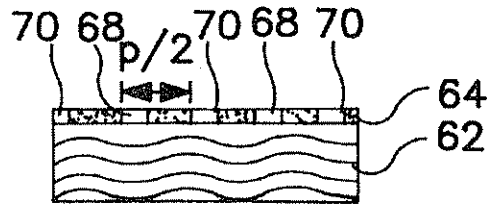


FIG. 10F



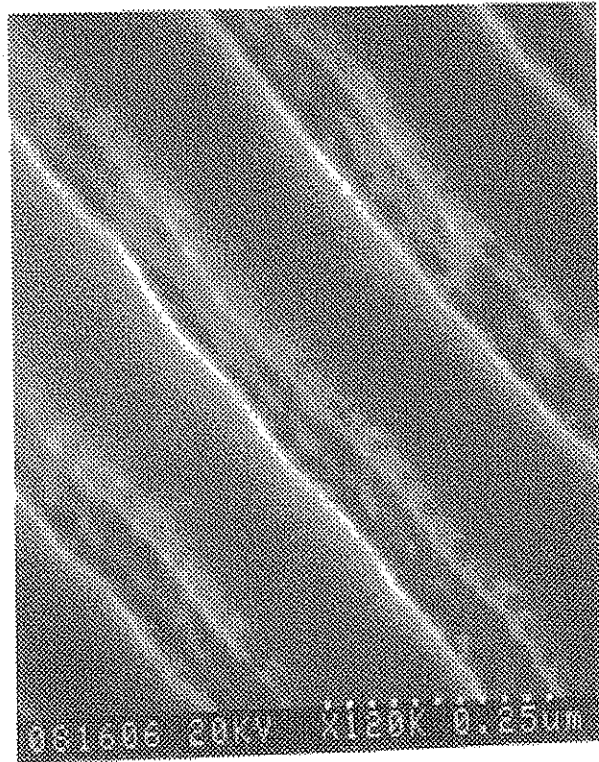


FIG. 11A

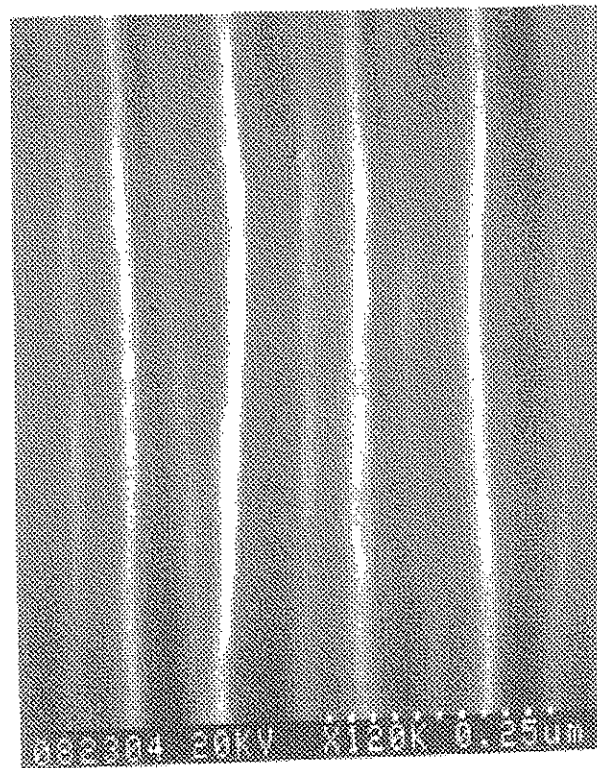


FIG. 11B

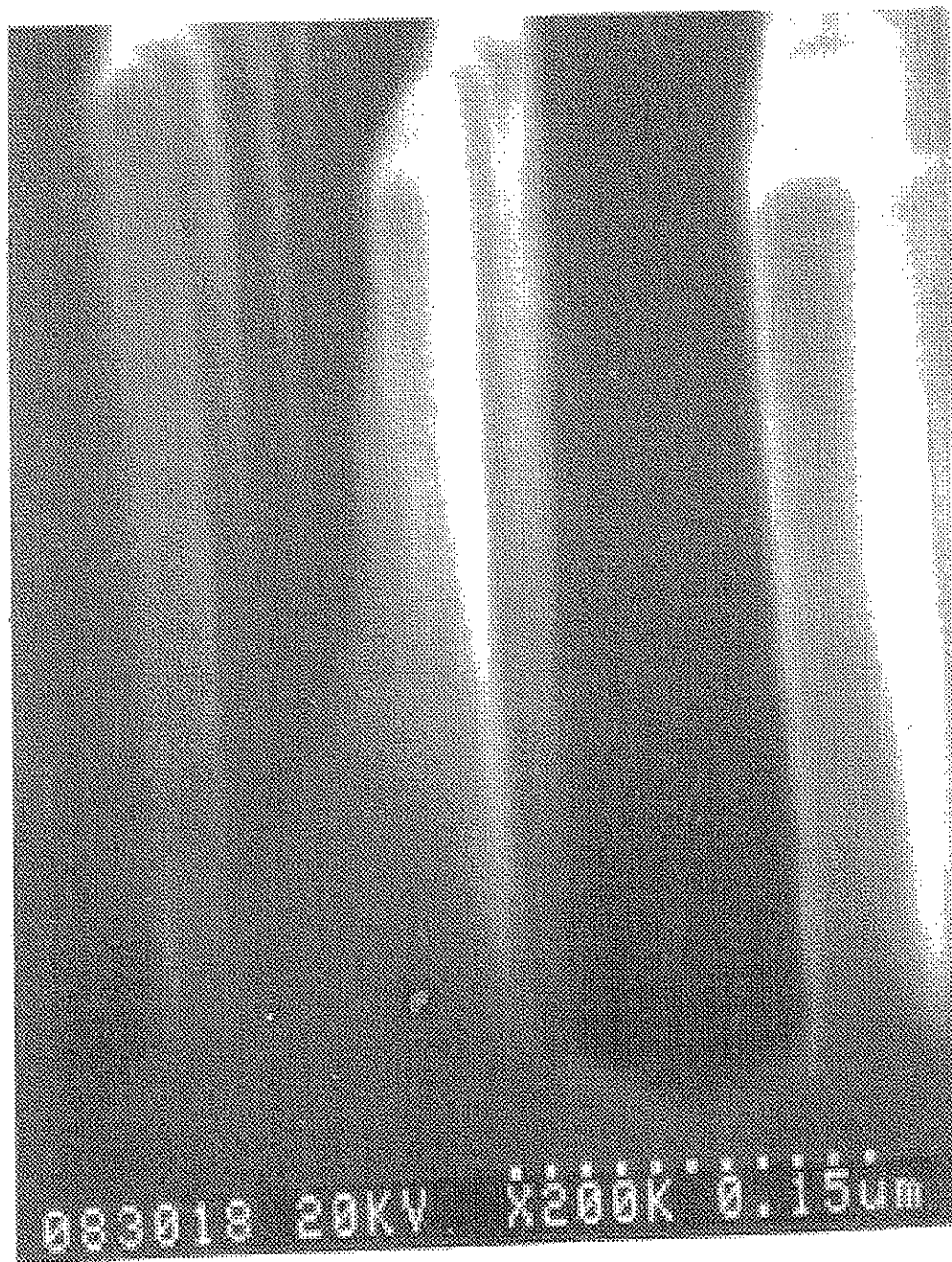


FIG. 11C