Microelectronic Engineering 135 (2015) 57–72

Contents lists available at ScienceDirect

Microelectronic Engineering

journal homepage: www.elsevier.com/locate/mee

Review Article

Nanofabrication by electron beam lithography and its applications: A review ☆

Yifang Chen

Nanolithography and Application Research Group, State Key Lab of ASIC and System, School of Information Science and Engineering, Fudan University, Shanghai 200433, China

ARTICLE INFO

Article history:
Received 1 August 2014
Received in revised form 30 January 2015
Accepted 20 February 2015
Available online 17 March 2015

Keywords:
Nanofabrication
Electron beam lithography
Nanostructure
Nanoelectronics
Nanophotonics
Metamaterial

ABSTRACT

This review covers a wide range of nanofabrication techniques developed for nanoelectronic devices, nanophotonic metamaterials and other nanostructures, based on electron beam lithography (EBL). Differing from earlier publications, this review particularly focuses on how to apply the property of EBL resists for constructing multilayer stacks towards pattern transfer. Most frequently used resists and their lithography property are first introduced, followed by categorizing multiple layers of resists for fulfilling various tasks in nanofabrication. Particularly, T shape gates for high electron mobility transistors (HEMTs), metallic tunneling junctions (MTJs) in single electron tunneling transistors (SETs), chiral structures and photonic crystals for optical metamaterials, templates for NIL and etching masks for nanoscale reactive ion etch (RIE) are reviewed. In the description of process development, scientific advances behind these fabricated nanostructures are described at the same time. By this way, this review aims to indicate that the development of nanofabrication techniques is essential for the rapid advances of nanoscience as a whole.

© 2015 Elsevier B.V. All rights reserved.

1. Introduction

The current top-down nanofabrication technique is, in practice, the pattern transfer at nanometer scale. Despite the large variety of nano processes, similar to well-developed semiconductor processes, nanofabrication at laboratory stage mainly involves nanolithography, dry etch, and/or lift-off of unwanted metal films that are deposited on patterned resists. Since the booming of nanolithography in 1980s, numerous nanolithography techniques have been developed, among which the state-of-the-art electron-beam lithography has been most widely implemented for patterning mesoscopic structures or systems with unique advantages of high resolution in feature size, high reliability in processing, high accuracy in positioning/alignment, and high flexibility in pattern replication. Nowadays, resolution capability as good as sub 10 nm by EBL has been repeatedly reported [1], which is fine enough to satisfy most of the demands as far as feature size concerned. Dry etch as opposed to wet etch which is difficult in dealing with nanostructures, belongs to the subtractive approach in pattern transfer following the replicated patterns by nanolithography. On the other hand, the lift off process after metal deposition belongs to the additive approach. These pattern transferring processes are the fundamental techniques to form the major nanofabrication techniques at the present. This review is to summarize the significant progresses in the development of these processes by EBL and demonstrate their wide applications.

2. Development of electron beam lithography and its applications

2.1. Processing study of electron beam lithography

Processing study in electron beam lithography (EBL) mainly covers resist property, resist profile control by EBL of either single layer or multiple layers, and pattern transfer by either lift-off or etch. In this part of the review, an overview of various common resists will be given at first, then three typical cases of processing study will be described.

2.1.1. EBL properties of most common resists

Up to date, the most common high resolution EBL resists can be categorized, according to their working principles, into two big groups, one contains PMMA (e.g. MW350K [2], MW100K [3]), PMMA/MAA [2], ZEP [4,5] and HSQ [6,7], etc. The other one, termed as chemically amplified resists (CARs), includes UVIII [8–10], UV1116 [11], UVN-30 [12–14], SU-8 [15], SAL-601 [16], NEB [17,18] and Calix[n]arene [19,20], etc. Resists in the first group can also be distinguished, according to their chemical structures,

☆ This article was submitted to the SI 'Micro and Nanofabrication Breakthroughs for Electronics, MEMS and Life Sciences'.

E-mail address: yifangchen@fudan.edu.cn

http://dx.doi.org/10.1016/j.mee.2015.02.042
0167-9317/© 2015 Elsevier B.V. All rights reserved.

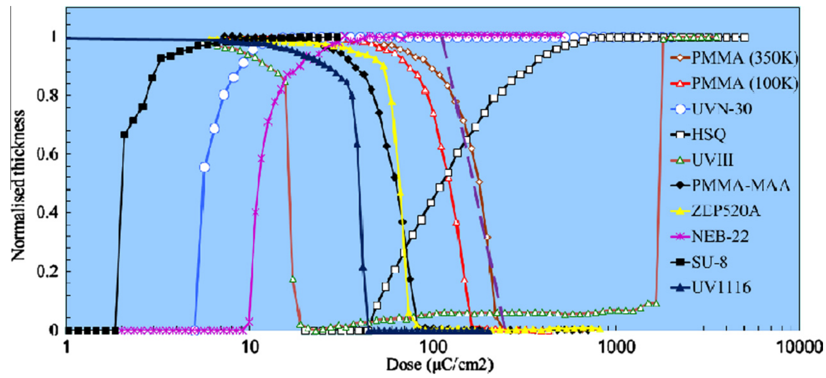

Fig. 1. Collections of contrast curves of most frequently used EBL resists by the author. The dash line with purple color is added as a guide for calculating the sensitivity and the contrast of a particular resist. In this particular figure, the line passes through two points of the PMMA (350 K) at 25% and 75% of the normalized remaining thickness, respectively. Its intersect point on the dose-axis measures the clearing dose (the reverse of sensitivity value) and its slope is the definition of contrast of the resist [5–22]. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 1
Comparison of lithography property for most frequently used e-beam resists.

Resist	Resist tone	Sensitivity (μC/cm^2)	Contrast	CD (nm)	Developer	Chemical structure	Refs.
PMMA (350 k)	Positive	230 (100 keV)	3–4	⩽5	MIBK:IPA, O-xylene	Poly methyl methacrylate	[10]
PMMA(100 k)	Positive	163 (100 keV)	3–4	⩽5	MIBK:IPA, O-xylene	Poly methyl methacrylate	[3]
PMMA–MAA	Positive	84 (100 keV)	3–4	~10	MIBK:IPA, O-xylene	Poly(methyl methacrylate-co-methacrylic acid)	[10]
UVIII	Positive	18 (100 keV)	11.8	~30	CD26	TMAH	[8,10]
UV1116	Positive	38–90 (100 keV)	10.4	30	CD26	TMAH	[11]
ZEP520	Positive	73 (100 keV)	7.8	~10	O-xylene	a-Hloromethacrylate + a-methylstyrene	[4,5]
UVN-30	Negative	5 (100 keV)	6	~90	CD26	Unavailable	[14]
HSQ	Negative	334 (100 keV)	1.1	⩽5	CD26, MIBK, TMAH	Hydrogen silsequioxane	[7,18]
SU-8	Negative	3–7 (100 keV)	3.5	20–30	EC solvent, cyclopentenone	8 epoxy groups	[15,18]
SAL-601	Negative	10–30 (50 keV)	5–6	60	TMAH	–	[16]
NEB	Negative	9–14 (50 keV)	4.7	Sub 10	CD26	–	[17,18]
Calix[n]arene	Negative	80–150 (50 keV)	1.5–1.9	10–20	MIBK	p-Methylcalix[n]arene	[19,20]

into organic (PMMA for example) and inorganic (HSQ) for the purpose of resolution enhancement. The Resist sensitivity and contrast are the two basic characteristics to describe its EBL property. Resolution, or minimum line-width in terms of critical dimension (CD) of a resist is certainly an important character, but it is strongly related to its environment (substrate, single or multiple layer, line-edge roughness, etc.), resist thickness and developing dynamics. Fig. 1 presents the contrast curves of these resists as a whole family picture for comparisons. The sensitivities and contrasts derived from these curves are concluded in Table 1. Also summarized in the table are the minimum critical dimensions (CD) of these resists. Fig. 2 is the bar chart of the feature size ranges of each family member. The concluded characteristics above can be used as a good guide for designing the resist layer stacks to fulfill various kinds of tasks for pattern transfer. Table 2 concludes the practical applications of these resists and their stacks.

In designing multiple layers of resists, three major kinds of profiles are desired as schematically shown in Fig. 3, respectively corresponding to three arrangements of sensitivity for the applications in undercut profile for lift-off [21], multistep profile for T shape gates [22] or Aztec configuration for structural color [23,24] and vertically periodical gratings for 1D photonic crystals as sensors [25]. The technical methods will be reviewed in the subsequent sections.

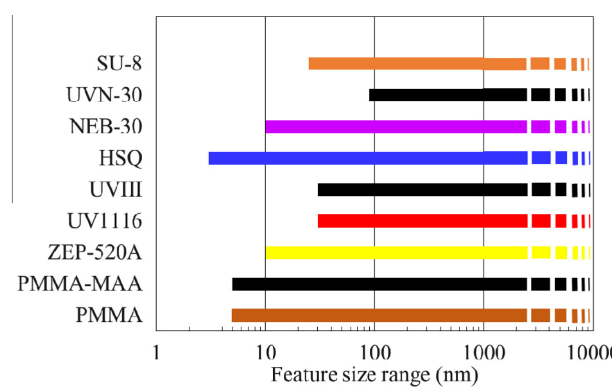

Fig. 2. The bar chart for the feature size ranges of the most frequently used e-beam resists. The resolution limit of each resist is from: Refs. [17,20] for SU-8, Ref. [16] for UVN-30, Refs. [19,20] for NEB, Refs. [9,20] for HSQ, Refs. [2,12] for UVIII, Ref. [13] for UV1116, Refs. [6,7] for ZEP-520A, Ref. [12] for PMMA–MAA and Ref. [12] for PMMA.

2.1.2. A hot developing process for dense HSQ patterns

In the resist family of EBL as described above, one of the frequently used resists is the inorganic resist, HSQ [26] for its broad applications such as a low permittivity (low-k) interlayer dielectric (ILD) in ICs technology [27], a resist in nanoimprint lithography [28], etch masks [29] in reactive ion etch, nanoscale metamaterials [28] and nanodevices [30,31], etc. Extensive studies have been attempted, including processing conditions such as curing temperatures [32], developer composition [33], aging and delay time before exposure [34]. In addition, developing conditions such as prebake temperature and developer concentration have been parametrically studied [35]. However, one of the key issues in the EBL of HSQ for dense patterns such as equal lines/spaces is the difficulty in removing the residual resist in between lines as shown in Fig. 4. Plasma etch had to be used with very limited effect but significantly deteriorated the lithography quality.

Download English Version:

https://daneshyari.com/en/article/6943542

Download Persian Version:

https://daneshyari.com/article/6943542

Daneshyari.com