Nano-fabrication of Superconducting Electrodes for New Type of LEDs

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Abstract Cold temperature development (CTD) of electron beam (EB) patterned resists and subsequent dry etching were investigated for fabrication of nano-patterned Niobium (Nb). Bulky Nb fims on GaAs substrates were deposited with EB evaporation. Line patterns on Nb cathode were fabricated by EB patterning and reactive ion etching (RIE). Size deviations of nano-sized line patterns from CAD designed patterns are dependent on the EB total exposure, but it can be improved by CTD of EB-exposed resist. Line patterns of 10 to 300 nm widths of EB-exposed resist patterns were drawn under various exposure conditions of 0.2 μs/dot (total 240,000 dot) with a constant current (50 pA). Compared with room temperature development (RTD), the CTD improves pattern resolution due to the suppression of backscattering effect. RIE with CF_4 was performed for formation of several nano-sized line patterns on Nb. Each EB-resist patterned samples with RTDs and CTDs were etched with two different CF_4 gas pressures of 5 Pa. Nb etching rate increases while GaAs (or ZEP) etching rate decreases as the chamber pressure increases. This different dependent of the etching rate on the CF_4 pressure between Nb and GaAs (or ZEP) has a significant meaning because selective etching of nano-sized Nb line patterns is possible without etching of the underlying active layer.

1. Introduction

EB evaporated Nb films have been exploring as an important material for application of superconducting light emitting diode (SLED) [1-4]. The superconducting LED is consists of Nb superconductor and semiconductor part, such as active layer (Ⅰ, Ⅱ) and InP buffer layer (Ⅲ) on InP substrate as shown Fig. 1.

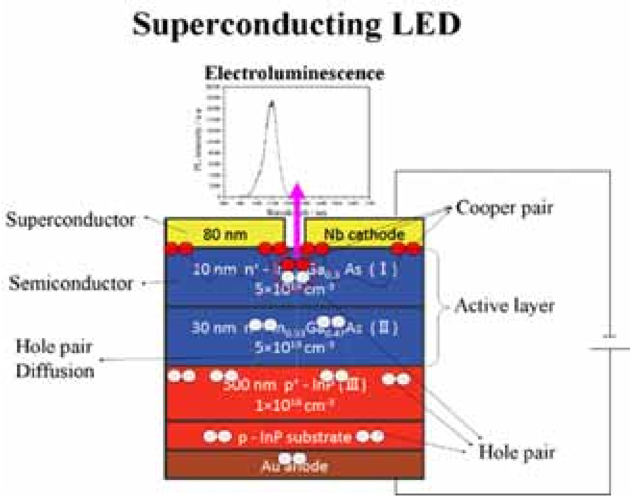

Fig.1 Superconducting Light Emitting Diode

2. Superconductor properties of Nb

Several attempts have been made to deposit Nb films with superconducting transition temperature (Tc) close to those reported for pure samples of bulk metals [5].

Superconducting transition temperature (Tc) of a few hundred nanometer thickness EB evaporated Nb films have been reported ~1K lower than pure bulk metal. Fig. 2 is indicated that their superconducting properties are sensitive to deposition condition.

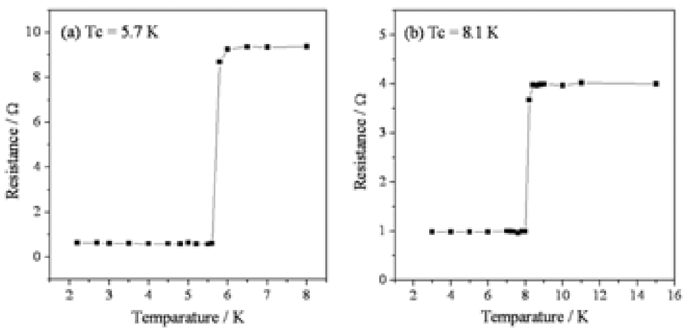

Fig. 2 (a) Cycle Deposition (Deposition 30 sec・Rest 30 sec, δ = 80 nm), (b) Continuous Deposition (δ = 80 nm)

3. Selective etching of Nb against GaAs

Selective etching of Nb slit should not damage sub-10nm sized thin InGaAs active layers below Nb.

Since the etching rate dependence on the CF_4 pressure for Nb is opposite for GaAs and ZEP, fabrication of Nb slit structures will be possible without etching of the underlying active layer as shown in Fig. 3.

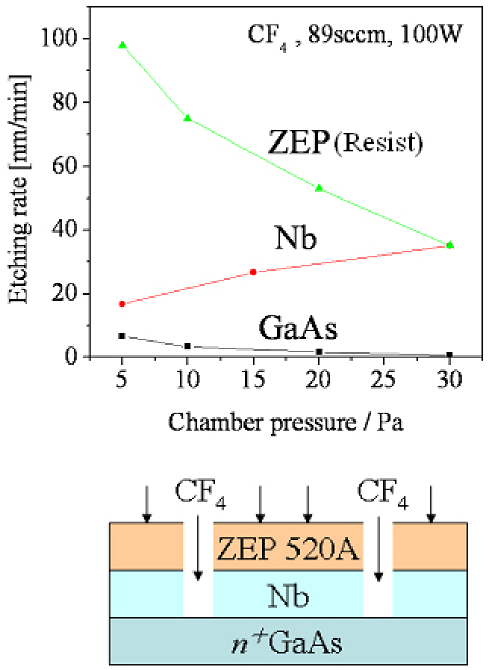

Fig.3 RIE-CF_4etching of ZEP/Nb/GaAs structure

4. CTD effect for nano-patterning

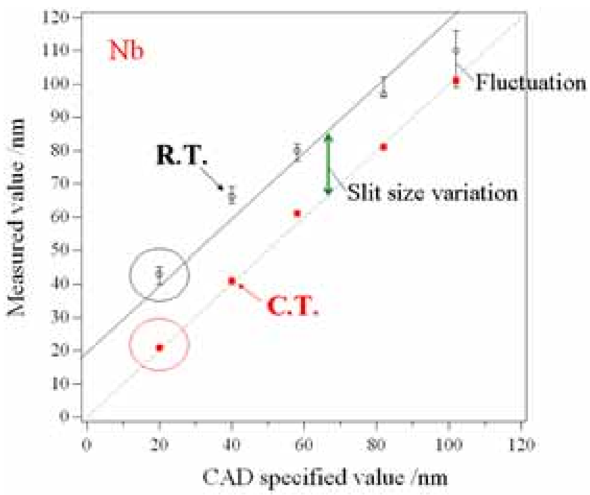

Fig.4 Slit size deviation between processed RTD and CTD and CAD designed value; CF_4 RIE etched Nb pattern by exposure amount of 0.2 μs/dot.

CTD would lead to high resolution, higher resist contrast. It is certified that there is significant reduction of ~20 nm in slit size deviation due to suppression of backscattering effect by CTD (Fig. 4). Such size variation should be explained by electrical field effect on ZEP resist, which is imposed by overlapping of forward and backward scattering as explained in Fig. 5.

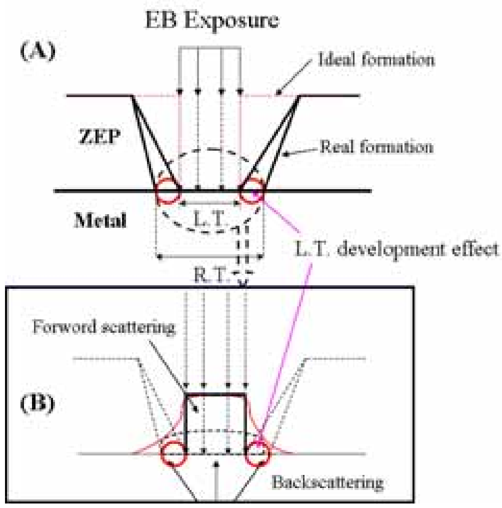

Fig.5 (a) ideal and processed ZEP formation by temperature development dependence after EB exposure, (b) electrical field effect on ZEP resist imposed by overlapping of forward and backward scattering.

Optimum feature size of line pattern can be related to dose (D) and number of exposure electrons (Ne) by the formula $L = (eN_e/D)^{1/2}$. The uncertainly limit so far is 2 % for all resists exposed at 100 kV. The CTD process also lines up with that limit when the exposure dose is scaled from 30 to 100 kV [6].

Reference

[1] I. Suemune, T. Akazaki, K. Tanaka, M. Jo, K. Uesugi, M. Endo, H. Kumano, E. Hanamura, H. Takayanagi, M. Yamanishi, H. Kan, *Jpn. J. Appl. Phys.*, 45, 12, 9264-9271, **2006**

[2] I. Suemune, T. Akazaki, K. Tanaka, M. Jo, K. Uesugi, M. Endo, Kumano, E. Hanamura, *Microelectron. J.*, 344-347, **2008**

[3] Y. Hayashi, K. Tanaka, T. Akazaki, M. Jo, H. Kumano, I. Suemune, *Appl. Phys. Exp. 1*, 011701(1-3), **2008**

[4] Y. Hayashi, K. Tanaka, T.Akazaki, M. Jo, H. Kumano, I. Suemune, *Phys.Stat.Sol.(C)* 5, 9, 2816-2818, **2008**

[5] D. Gerstenberg, P.M. Hall, *J. Electrochem. Soc.*, V 111, N8, 936-942, **1964**

[6] L.E. Ocola and A. Stein: Effect of cold development on improvement, *J. Vac. Sci. Technol. B*, Vol. 24, No. 6, Nov/Dec, 3061-3065, **2006**