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Reducing insulating substrate charging in electron beam lithography without using charge dissipation layer

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We investigate charging effect in electron beam lithography for patterning resist on electrically insulating substrate. We find that the charging effect can be mitigated without using a charge dissipation layer with an optimized exposure writing order strategy. We successfully fabricate an AlGaAs-on-sapphire (AlGaAsOS) miroresonator with intrinsic quality factor (*Q*) as ~180,000 with the optimized EBL process.

Electron beam lithography (EBL) is a common lithography technique for patterning micro- and nano-scale semiconductor devices for electronics and photonics applications. EBL suffers from charging effects when the device substrates are electrically insulating materials such as glass and sapphire [1]. Because of static electric charges accumulated during EBL, the following arrived electron will be deflected which results in pattern distortion. The problem becomes worse when a low-sensitivity electron beam resist such as hydrogen silsesquioxane (HSQ) is used as an etching mask. A thin metal layer can be deposited on top of resist as a charge dissipation layer to solve the charging issue. However, a wet etch is typically used to remove the metal film, which raises concerns about chemical compatibility with the resist or substrate materials. Other methods like using variable pressure EBL [1], ion shower [2], and conductive polymer [3] can be used but also require additional processing steps, which complicate the whole fabrication process.

In EBL systems, pattern generators fracture device patterns into segments that will be exposed to electrons in a certain sequence. We investigate the influence of the exposure writing order and we find out the charging effect can be mitigated by using an optimized writing order strategy. Writing order strategies at sub-field level and segment level are examined for patterning microring resonators in HSQ on AlGaAs-on-sapphire (AlGaAsOS) wafers, which has been demonstrated as an ultra-efficient nonlinear integrated platform for nonlinear photonics applications [4, 5]. The AlGaAsOS samples are spin-coated with a 350-nm thick HSQ (FOX-15) layer and then microring patterns are exposed in 100-keV EBL system (JEOL JBX-9500FS) (12000 μC/cm^2 dose, 6 nA current). Patterns are fractured by GenISys software BEAMER. Fig. 1 compares the exposure writing order at sub-field level for patterning 34-μm diameter ring patterns. The default writing order strategy in the JEOL system is "raster scanning" along a certain axis as shown in Fig. 1(a). The writing order "follow geometry" ensures the pattern are defined consecutively following the device pattern direction as shown in Fig. 1(b). Fig. 1(c,d) shows the scanning electron microscopy (SEM) pictures for developed patterns and severe pattern distortions was observed for "raster scanning" strategy while the "follow geometry" strategy allows for a smooth pattern definition. Fig. 2 compares the exposure writing order at segment level for patterning 3-μm diameter ring patterns. For the writing order "array compaction", the exposure jumps between segments as shown in Fig. 2(a), which results in severe segment placement errors (see Fig. 2(c)). Smooth patterning can still be obtained in the case of "follow geometry" as shown in Fig. 2(b, d). We use this optimized writing order to fabricate a 17-μm radius AlGaAsOS microring resonator with an integrated bus waveguide as shown in Fig. 3 exhibiting an intrinsic *Q* up to 180,000.

In conclusion, we find that exposure writing strategy is critical element in EBL and "follow geometry" writing order can be utilized to mitigate charging effect in resist without applying CDL. With the optimized writing order in EBL, the fabrication process for devices residing on insulating substrate is simplified.

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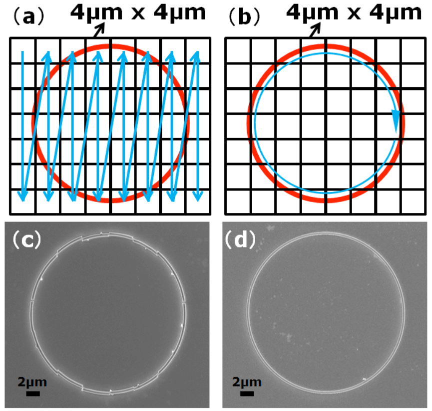

Figure 1. Comparison for subfield exposure writing orders: (a,c) "raster scanning" and (b,d) "follow geometry" (c, d) shows the defined HSQ patterns after EBL and resist development.

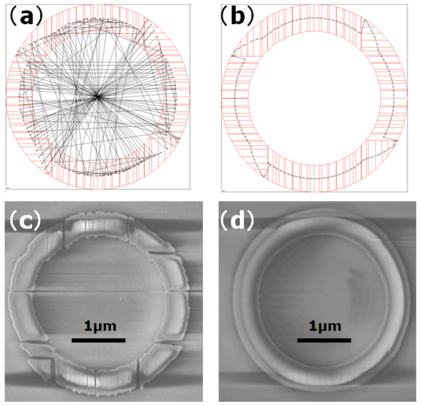

Figure 2. Comparison for segment exposure writing orders: (a,c) "array compaction" and (b,d) "follow geometry" (c,d) shows the defined HSQ patterns after EBL and resist development.

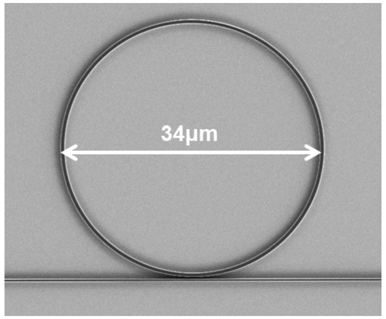

Figure 3. Fabricated 17-μm microring resonators in AlGaAs-on-sapphire platform with applying "follow geometry" writing order in EBL without CDL.

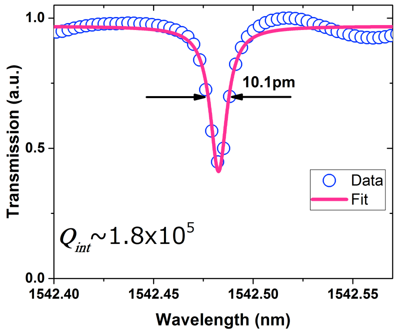

Figure 4. Measured transmission spectrum around the resonance of the fabricated AlGaAsOS microresonator around 1542.5 nm showing an intrinsic *Q* of ~180,000.