Reactive Ion Etching of Low-Loss Channel Waveguides in $\text{Al}_2\text{O}_3$ and $\text{Y}_2\text{O}_3$ Layers

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Aluminum oxide and yttrium oxide thin films are known to be excellent hosts for rare-earth ions and prospective materials for active integrated optical applications [1]. Both materials have sufficiently large refractive indices for the realization of highly compact integrated optical devices. They also have a high transparency, which is required for low-loss optical waveguides and achieving sufficient gain in active devices. In order to realize high-quality integrated active waveguide devices in low-loss $\text{Al}_2\text{O}_3$ and $\text{Y}_2\text{O}_3$ layers, a reliable patterning technique is required. Both $\text{Al}_2\text{O}_3$ and $\text{Y}_2\text{O}_3$ possess very high mechanical and chemical stabilities, which makes them more challenging to structure than many other common dielectric materials. Previously, either Ar-ion beam milling [2][3] or wet chemical etching [4][5] have been used to define ridge waveguide structures in $\text{Al}_2\text{O}_3$ and $\text{Y}_2\text{O}_3$ layers. However, both techniques (physical etching via Ar-ion beam milling and wet chemical etching) limit both the overall resolution of the process and the steepness of the sidewall profile. Furthermore, the etch depths in $\text{Al}_2\text{O}_3$ were limited to 300 nm using Ar ion milling and less than 400 nm in the case of wet etching, while the structures obtained using Ar-ion beam etching in $\text{Y}_2\text{O}_3$ were limited to 2-µm widths and only very shallow etch depths (< 100 nm) were reported.

In this work, the etching behaviour of reactively co-sputtered amorphous $\text{Al}_2\text{O}_3$ and polycrystalline $\text{Y}_2\text{O}_3$ films was investigated using an inductively coupled reactive ion etch system. Various common process gases and combinations of these gases, including $\text{CF}_4/\text{O}_2$, $\text{BCl}_3$, $\text{BCl}_3/\text{HBr}$, $\text{Cl}_2$, $\text{Cl}_2/\text{Ar}$ and Ar, have been applied. As shown in Fig. 1, the observed etch rates of $\text{Al}_2\text{O}_3$ films were much higher than $\text{Y}_2\text{O}_3$ for all process gases except for Ar, indicating a much stronger chemical etching component for the $\text{Al}_2\text{O}_3$ layers. In addition, the etch rates of various possible mask materials in the same process gases were measured. Based on these data and an investigation of the selectivity and patterning feasibility of the potential mask materials, optimized optical channel-waveguide structures were fabricated in both materials. In $\text{Al}_2\text{O}_3$ channel waveguides were fabricated with $\text{BCl}_3/\text{HBr}$ plasma and using a standard resist mask, while in $\text{Y}_2\text{O}_3$ channel waveguides were fabricated with Ar and using either a resist or sputter deposited $\text{Al}_2\text{O}_3$ mask layer. SEM micrographs of the resulting waveguide structures are shown in Fig. 2. The etched structures in both materials exhibit straight sidewalls with minimal roughness and sufficient widths (down to 1.0 µm for $\text{Al}_2\text{O}_3$ and 1.4 µm for $\text{Y}_2\text{O}_3$) and etch depths (up to 530 nm for $\text{Al}_2\text{O}_3$ and 250 nm for $\text{Y}_2\text{O}_3$) for defining waveguides with strong optical confinement. Using the developed etch processes, single-mode ridge waveguides were fabricated in both $\text{Al}_2\text{O}_3$ and $\text{Y}_2\text{O}_3$ layers and the optical losses of the channels were measured using a broadband (1520-1580 nm) source with fiber coupling setup and the cut-back technique. The additional losses introduced by etching, as determined by subtracting the known background losses of the un-etched films from the measured channel losses, were found to be low (< 0.5 dB/cm). Currently, the processes developed in this work are being used in the fabrication of integrated active waveguide devices in rare-earth-ion doped $\text{Al}_2\text{O}_3$ and $\text{Y}_2\text{O}_3$ layers.

References:
Figure 1. Comparison of (a) Al\textsubscript{2}O\textsubscript{3} and (b) Y\textsubscript{2}O\textsubscript{3} etch rates as a function of RF power in CF\textsubscript{4}:O\textsubscript{2} (90\%:10\%), BCl\textsubscript{3} (100\%), BCl\textsubscript{3}:HBr (50\%:50\%), Cl\textsubscript{2} (100\%) and Ar (100\%).

Figure 2. SEM micrographs of (a) a 1.3-μm-wide and 530-nm-deep channel waveguide in Al\textsubscript{2}O\textsubscript{3} and (b) a 250-nm-deep Ar-etched channel waveguide in an 800-nm-thick Y\textsubscript{2}O\textsubscript{3} film.