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Wet Oxidation of AlGaAs vs. AlAs: A Little Gallium is Good

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Abstract

We show buried oxides converted from AlGaAs alloys, rather than AlAs, are superior in terms of oxidation isotropy, mechanical stability, and lack of strain. Oxidation of AlGaAs layers provide robust oxide apertures for reliable vertical-cavity lasers.

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We report significant differences between buried oxides converted from AlGaAs alloys versus AlAs using selective wet oxidation. These oxides have recently been employed in edge emitting lasers[1], vertical-cavity surface emitting lasers (VCSELs)[2,3], optical waveguides[4], and metal-oxide-semiconductor transistors[5]. The oxides have been commonly formed from AlAs layers, presumably due to the ease of growth of the binary compound. However preliminary reports using oxidized AlAs layers in VCSELs described operating lifetimes of several minutes[2], while robust VCSELs have been achieved using oxidized AlGaAs layers[6]. We show oxides converted from AlGaAs are superior in terms of oxidation isotropy, mechanical stability, and lack of strain.

The properties of partially laterally oxidized $Al_xGa_{1-x}As$ layers with $0.92 \le x \le 1.0$ contained within a monolithic VCSEL are examined[3,6]. Top views of VCSEL mesas using different AlGaAs alloys in the oxide aperture layers are shown in Figs. 1(a)-(c). The region in the mesa center corresponds to the unoxidized portion of the current aperture which defines the laser cavity. Independent of composition, the current aperture resulting from a square mesa tends to be square as in Fig. 1(a) [3]. However, for high Al-content layers ($x \ge 0.94$) crystallographic oxidation dependence can be observed from circular mesas as seen in Fig. 1(b). The oxidation rate along the <010> crystal directions is faster than along the <110> directions, consistent with the lower surface reactivity of (110) planes[7]. With the addition of sufficient Ga, isotropic oxidation can be achieved as shown in Fig. 1(c), revealing a circular aperture from a circular mesa for x=0.92.

The mechanical stability of mesas which contain buried layers which have been partially oxidized are also found to depend upon the layer composition. Shown in Fig. 2 is a comparison of oxidized VCSEL mesas which have been subjected to rapid thermal annealing to 350°C for 30 sec. The mesas containing $Al_{0.98}Ga_{0.02}As$ in the oxide layer (Fig. 2(a)) are unaffected by the anneal, while the mesas containing oxidized AlAs (Fig. 2(b)) delaminate along the oxide/semiconductor interface. This structural thermal sensitivity is also observed in other post-oxidation VCSEL processing steps which require temperatures of ≈100°C or greater. A cross section transmission electron microscopy (TEM) image of an AlAs oxide current aperture is shown in Fig. 3. At the terminus of the oxide layer clear evidence of a strain field is observed (see arrow). In contrast, for $Al_{0.98}Ga_{0.02}As$ oxide layers no evidence of strain or other extended defects are apparent[6]. The strain in Fig. 3 presumably arises from the volume shrinkage in the oxidized AlAs layer: the γ-Al_2O_3 converted from AlAs has a measured[8] (theoretical) volume contraction of >12% (20%) as compared to the original AlAs layer. By comparison, the volume shrinkage of oxides formed from $Al_xGa_{1-x}As$ for x=0.92 and 0.98 have been measured to be 6.7% [9]. The mechanical instability of mesas containing AlAs oxide layers as in Fig. 2(b) and the strain observed at the AlAs oxide terminus as in Fig. 3 are indicative of excessive stress in the oxidized structures. The addition of a small amount of Ga to the oxidation layer is found to mitigate these adverse effects.

In summary, buried oxides formed from the wet oxidation of AlGaAs alloys, rather than AlAs, are found to be superior in terms of oxidation isotropy, mechanical stability, and strain. It is not surprising that VCSELs using AlGaAs oxide layers as current apertures have shown promising reliability as compared to VCSELs using AlAs layers. Comparisons of lifetime data for VCSELs with differing oxide layers will be presented. The beneficial properties of oxides converted from AlGaAs alloys are found to provide robust device processing of reliable VCSELs and may play an important role in other advanced optoelectronic devices.

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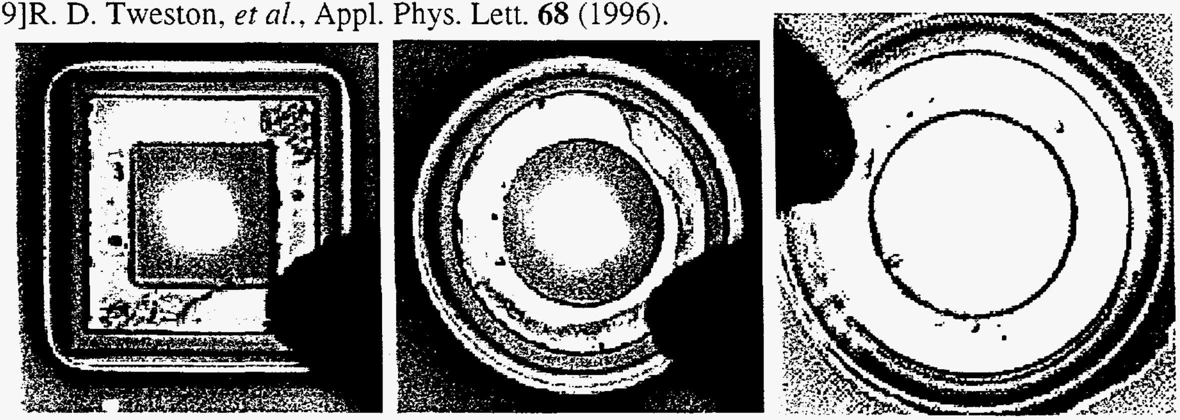
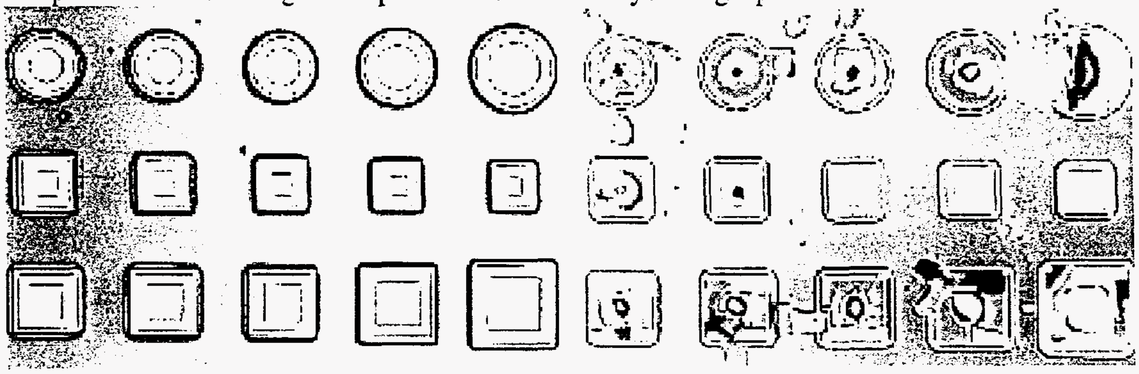


(a) (b) (c)

Fig. 1. (a) Top view of a VCSEL mesa with $Al_{0.98}Ga_{0.02}As$ current aperture (center region surrounded by metal contact); (c) circular mesa with AlAs current aperture; (d) circular mesa with $Al_{0.92}Ga_{0.08}As$ current aperture. Photo edges are parallel to <110> crystallographic directions.



(a) (b)

Fig. 2. Top view of VCSEL mesas after rapid thermal annealing to 350°C for 30 sec which contain $Al_xGa_{1-x}As$ oxide apertures with: (a) x=0.98, and (b) x=1.0.

Fig. 3. Cross section TEM image of AlAs oxide aperture where arrow denotes the oxide terminus.