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Technique for fabrication of alignment grooves in $LiNbO_3$ substrates for simplified optical fibre pigtailing.

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Abstract.

We report a technique for fabricating alignment grooves in $LiNbO_3$ substrates, for simplified optical fibre attachment. The grooves are produced through etching of material that has been domain inverted, via spatially selective electric field poling. The etched grooves are of very high surface quality, and have a profile that is determined by the area of domain inversion produced. The technique lends itself to a method of fibre alignment that is both simplified, more reliable, and less labour intensive than existing schemes.

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$LiNbO_3$ is widely used for a range of optoelectronic applications in both bulk and waveguide formats. In the telecommunications area, $LiNbO_3$ is the current material of choice for construction of high speed modulators, usually fabricated as an integrated optoelectronic package which requires subsequent fibre-pigtailing for connection to the external fibre network. Unlike silicon, in which alignment V-grooves can be accurately and reliably fabricated via its highly anisotropic etch characteristics, $LiNbO_3$, in the normal single-domain state required for modulator applications, does not display any such equivalent anisotropy. There is considerable commercial interest therefore in any process that can facilitate fiberisation to such devices, to reduce both the bottleneck of such labour-intensive production, and the consequent high packaging costs, which represent of order 40% of total component cost.

Recent techniques for improved fiberisation to optoelectronic components range from controllable excimer laser machining of slots, for improved passive alignment to $LiNbO_3$ substrates [1], to the use of miniature (few mm^2) in-package electronically controllable microelectromechanical aligners, that can deflect a fibre tip over distances of a few tens of μm [2]. These techniques, whilst an improvement on existing manual alignment procedures, still do not offer the equivalent simplicity of lithographically-defined V-groove fabrication in silicon.

In this letter, we describe a simplified process for the fabrication of alignment grooves, that only requires the two additional steps of domain poling and differential etching, to precisely define the position and depth of the required fiber alignment structures. Both these processes are compatible with existing clean-room fabrication procedures, and utilise conventional photolithographic patterning steps.

The $LiNbO_3$ samples used were supplied by Koto Electric (Japan) as z-cut, 76 mm diameter. 500μm thick wafers. The wafers were subjected to multiple cleaning steps, involving ultrasonic agitation at elevated temperature (50°C), dried, and spin coated with photoresist on to the -z crystal face, producing a 1.1 μm thick film. After baking at 90°C for 30 minutes, the photoresist surface was patterned using conventional chrome on quartz masks. The wafer samples were then poled, by application of an external electric field of 22.5kV mm^{-1}, using in-situ monitoring of poling current to ensure optimal domain reversal [3]. Finally, the samples were thoroughly cleaned using acetone and deionised water.

$LiNbO_3$ is a ferroelectric crystal, which can exist in one of two possible 180° oriented domain states. The etch rate for the +z and -z crystal faces is very different, for samples immersed in an etchant solution consisting of a mixture of $HF{:}HNO_3$ acids in a 1:2 volume ratio. We have previously characterised this highly anisotropic etch behaviour, establishing that while the -z face can etch relatively quickly, at a rate of ~55 μm per hour at the elevated temperature of 110°C [3], the −z face remains completely unetched, leading to an exceptionally large differential etch rate between these +z and -z crystal faces. We have since used this technique to fabricate low loss, ~0.8 dB cm^{-1}, ridge waveguides in $LiNbO_3$, for use in lasing and modulator structures [4].

With reference to figure 1, photoresist patterning and mask exposure, fig 1(a), produces a slot of the appropriate width to match the typical 125 μm diameter of standard telecom fiber. Electric field poling can subsequently generate the required region of domain inverted material, fig 1(b), which can then be controllably etched in the $HF{:}HNO_3$ acid mixture, to yield the alignment structure shown in fig 1(c). Both width, and depth of the slot produced is under experimental control via the initial photoresist slot width, and the etchant temperature and time. Note that the etched alignment feature, while approximating to a V-groove profile, actually has a facetted bottom face, thereby enabling contact to be established at four places between fiber and substrate, rather than the more usual two as in conventional silicon V-grooves: this favourable etch characteristic is further emphasised in figure 2. Sawing the wafer in half, fig 1(d), finally yields two devices, each with its own alignment groove. Figure 3 shows a scanning electron microscope picture of an assembled pigtailed device, which has had a 125µm diameter telecom fibre attached. The benefits to this technique therefore indicate a much simpler process for fiberisation.

The final point concerns the quality of the endfaces of the etched alignment grooves. As discussed before for both excimer laser machined grooves in $LiNbO_3$ [1], and silicon V-grooves [5], a saw cut can be used to remove a thin slice of material at the end of the groove, thereby allowing precise contact between the cleaved fiber end and the waveguide structure. The diamond saw cut depth and width used in [1,5] were of order 100µm and 200µm respectively. We anticipate adopting this as a final machining step, if the end face of the groove shows any appreciable deviation from the vertical.

In summary therefore, we have illustrated the advantages, and described the simplicity of this novel domain orientation sensitive etching technique. The benefits in reduction of fabrication steps, and simplicity of optimisation of groove width, depth and profile have been outlined, and should lead to a net reduction in packaging and component assembly costs.

References.

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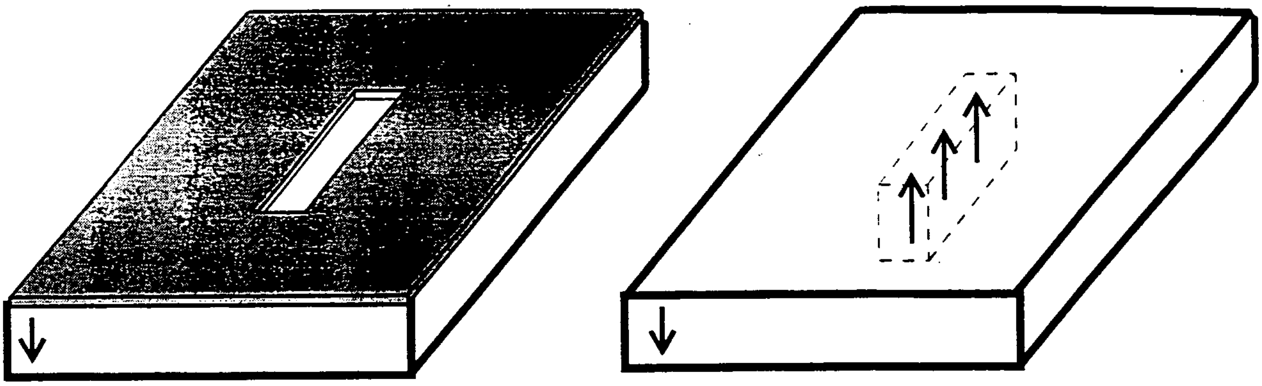
Figure Captions.

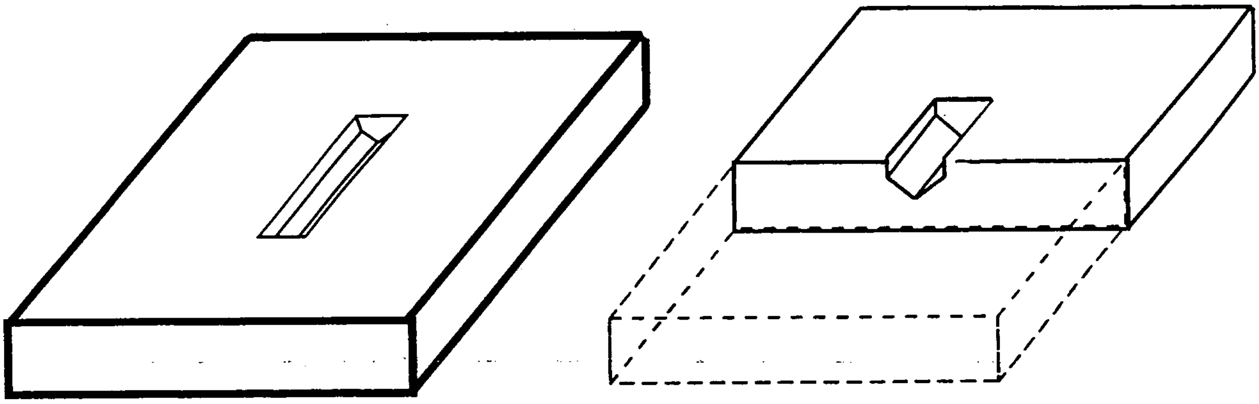
1. Steps in fabrication process of alignment grooves in $LiNbO_3$.

2. Profile of V-groove in silicon (a) versus modified V-groove in etched $LiNbO_3$ (b).

3. Scanning Electron Microscope picture of pigtailed device using a standard 125 μm diameter telecom fiber.

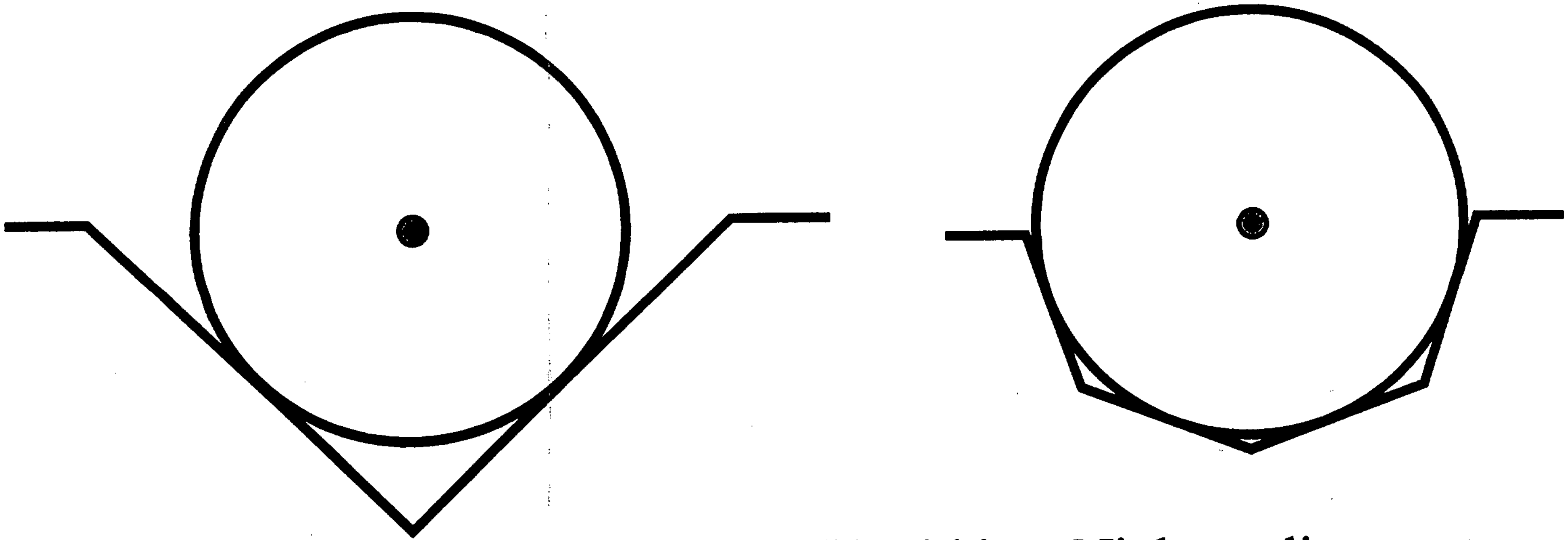


(a) Photoresist patterning (b) Domain inversion



(c) Domain orientation selective etching (d) Sawing in half

fig 1



(a) Silicon V-groove (b) Lithium Niobate alignment groove

fig 2

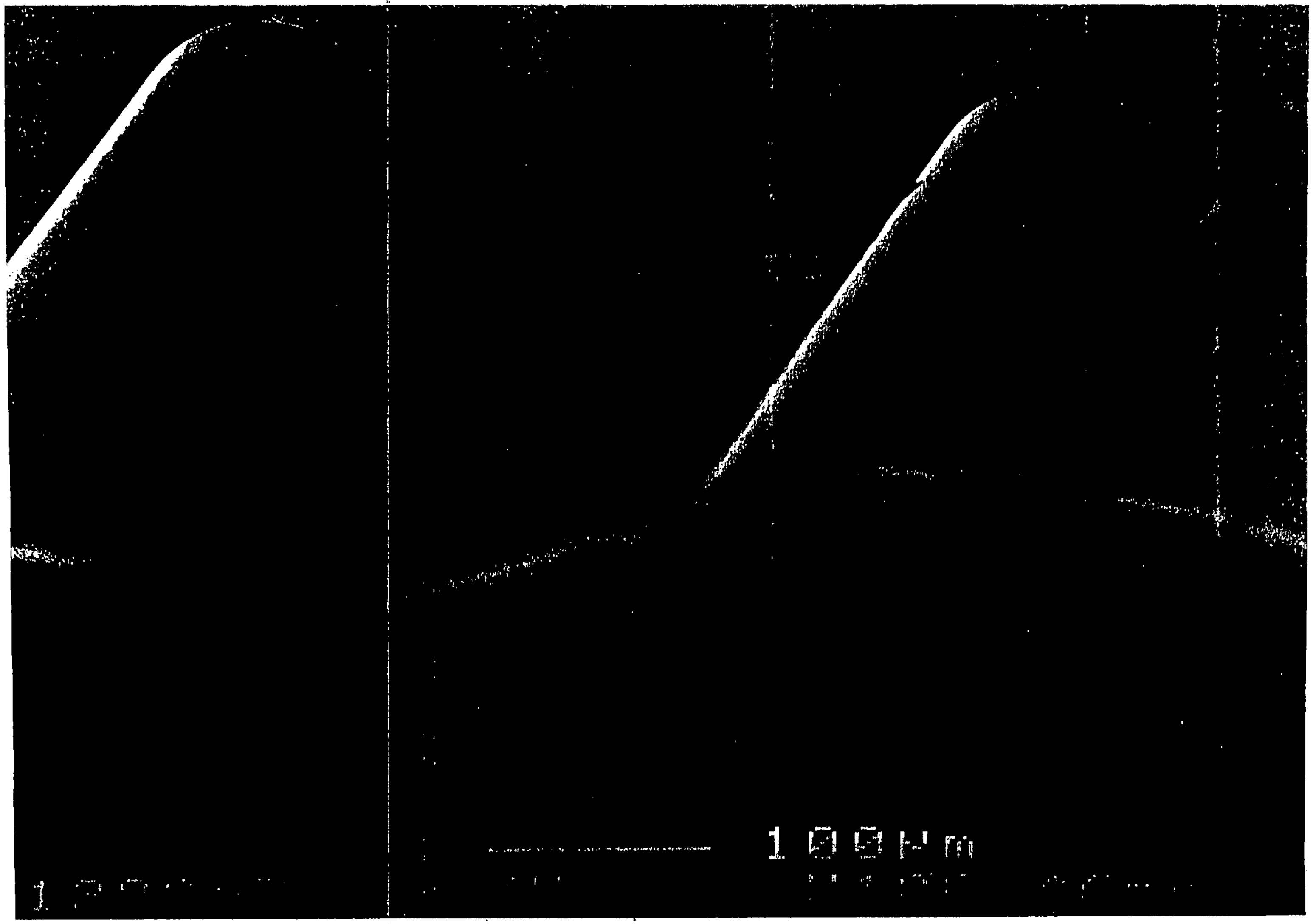


fig3.