Thin, flexible waveplate of fluorinated polyimide

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A thin optical half-waveplate at 1.55μm, only 14.5μm thick, which is 6.3 times as thin as a zeroth order quartz waveplate, is prepared using fluorinated polyimide This material has good flexibility, thickness controllability, and high thermal stability The retardation of the waveplate was retained after annealing at 350°C for 1 h

Introduction The most commonly used birefringent materials for optical components are calcite and quartz Such inorganic crystals have high optical transparency and good thermal and environmental stability However, their birefringence cannot be varied and they are difficult to make into thin plates or small components The thickness of a zeroth order calcite half-waveplate for the long distance optical communication wavelength (1.55μm) is ~5μm, making the waveplate almost impossible to grind and polish because of its fragility On the other hand, the low birefringence of quartz makes the half-waveplate thick (92μm) This results in considerable excess loss when the waveplates are inserted into waveguides [1] There has been a strong demand for new optical materials whose birefringence can provide a half-waveplate 10–20μm thick while having good processability and tractability

Uniaxially drawn Kapton®-type poly(amic acid) film [2] can give a highly oriented polyimide film with a large in-plane birefringence of 0.18, which is larger than that of calcite In this study, we investigated fluorinated polyimides as a novel birefringent material whose thickness and retardation can be precisely controlled Fluorinated polyimides [3, 4] exhibit high transparency in the visible near-infra-red region, and have high thermal stability (above 300°C), and low water absorption (0.2–0.7wt%) These characteristics are superior to those of conventional nonfluorinated polyimides, such as Kapton®, which have high water absorption of ~2–3wt%, which causes optical loss at optical communication wavelengths

Sample preparation and measurement The fluorinated polyimide, PMDA/TFDB (Fig 1), used in this study has a rod-like structure accompanied by a large anisotropy in electronic polarisability This is advantageous for generating large in-plane birefringence by uniaxial drawing The preparation of poly(amic acid) of PMDA/TFDB has been described in detail elsewhere [4] The films of poly(amic acid)s were prepared by spin-coating N,N-dimethylacetamide solution onto a 4 inch silicon wafer, followed by drying in nitrogen at 70°C for 1h The film was then peeled from the substrate, two of its sides were cut off, and it was fixed in a metal frame by the other sides (Fig 2) The film was 55mm long (in the fixed direction) and 60mm wide The film was then heated to 350°C at 4°C/min to convert the poly(amic acid) into polyimide As the temperature increases, the polymer chains spontaneously orient along the fixed direction as a result of the tensile stress arising from the shrinkage of the polymer film and the evaporation of the solvent Hence the oriented polymer chains exhibit in-plane birefringence

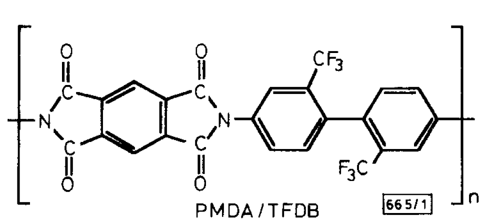

Fig. 1 *Fluorinated polyimide for optical waveplate*

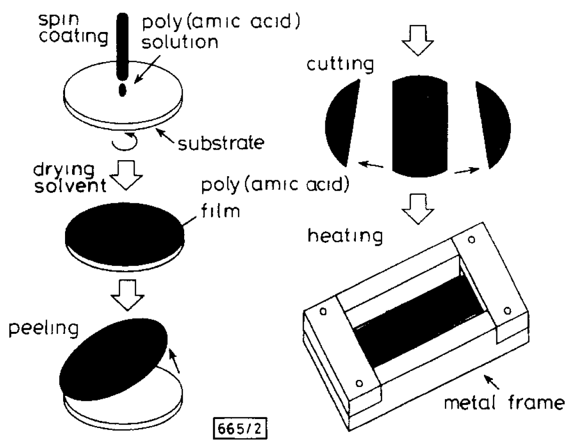

Fig 2 *Method of fabricating in-plane birefringent polyimide films*

The retardation of the films was directly measured by the parallel Nicole rotation method at 1.55μm, and thickness was measured from the interference fringe observed in near-infra-red absorption spectra (wavelengths 1.6 – 2.6μm) The retardation and the thickness were measured at the centre of the films In-plane birefringence (Δn) was calculated by dividing the retardation by the thickness The largest in-plane refractive index (n_{TE1}) and the smallest in-plane refractive index (n_{TE2}) at 1.523μm were measured using a Metricon PC-2000 refractometer

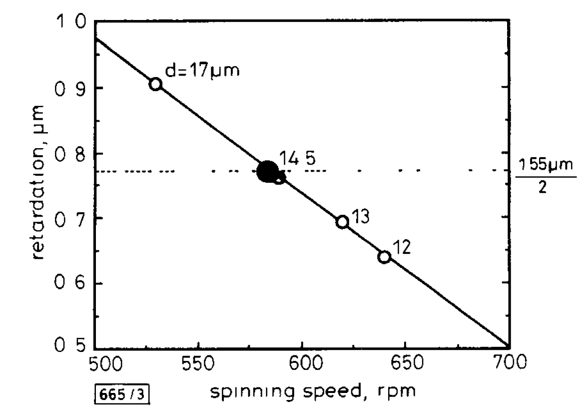

Fig 3 *Retardation of polyimide films against speed of spin coating*

Waveplate fabrication The Δn, n_{TE1}, and n_{TE2} of the film prepared by the above method are 0.053, 1.638, and 1.585, respectively The film was very pale yellow, tough, and flexible Because retardation is the product of the thickness and in-plane birefringence, precise control of retardation requires film thickness control It is well known that the thickness of polyimide film can be controlled by changing the spinning speed of the poly(amic acid) solutions As shown in Fig 3 the retardation of the polyimide films is linearly proportional to the spinning speed From Fig 3, the spinning speed for producing a half wavelength retardation at 1.55μm should be 570rpm The retardation of the film thus obtained was 0.772 This indicates that the retardation of fluorinated polyimide films can be controlled to have an error of less than 1% In addition, the half-waveplate was only 14.5μm thick, which is 6.3 times as thin as a quartz waveplate This will decrease the excess loss caused by inserting waveplates into waveguides An attempt to use this polyimide waveplate as a TE/TM mode convertor in silica-based planar lightwave circuits is under way [5] An important feature of retardation is thermal stability, in order to provide compatibility with high performance optical circuits We examined the thermal treatment effect by annealing half waveplates prepared by the above method at 250, 300, 350, 380, and 400°C for 1h As shown in Fig 4, the retardation of the waveplates does not change below 350°C, the preparation temperature of polyimides Above 350°C, the retardation increases with annealing, suggesting that self-orientation of polyimide molecules takes place

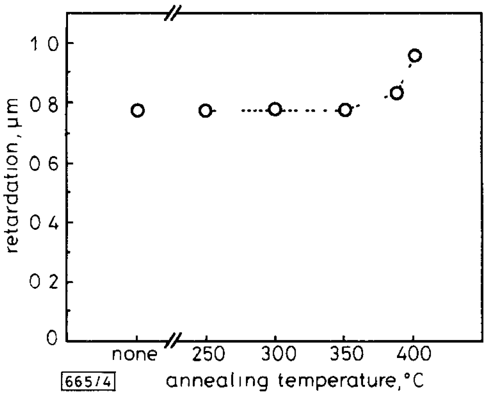

Fig. 4 *Retardation of polyimide films after annealing for 1 h*

Conclusion Fluorinated polyimide is a novel in-plane birefringent optical material that can be used to make a half-waveplate at 1 55µm that is only 14 5µm thick This waveplate is flexible and tough and has a large in-plane birefringence The optical retardation of the polyimide could be controlled within 1% by adjusting the spin-coating speed The waveplate was 6 3 times as thin as a quartz waveplate, which will decrease the excess loss due to the insertion of waveplates into waveguides The retardation of the waveplate was retained after annealing at 350°C for 1 h

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