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TECHNICAL MEMORANDUM

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AN IMPROVED PRISM FOR USE IN LASER RESONATORS

J. RICHARDS

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S U M M A R Y

The use of compound total internal reflection prisms rather than Porro prisms in polarisation coupled lasers is proposed. Performance advantages resulting from the use of these prisms include higher output without the need to bias the Pockels cell, ability to give a larger range of output coupling and independence of performance on the refractive index of the prism. In conventional Q-switched lasers the use of the prism at the Pockels cell end of the resonator instead of the usual 100% reflecting mirror also leads to some advantages including better hold-off, elimination of the need to bias the Pockels cell and insensitivity in one plane to angular misalignment.

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1. INTRODUCTION

Lasers employing Porro prism reflectors, for example the crossed-Porro laser(ref.1,2) are finding favour in military applications due to their insensitivity to mechanical shocks and vibration. The use of Porro prisms in such lasers can lead to some limitations in the maximum output obtainable using simple Pockels cell driving circuits and in the range of output coupling possible. Taylor(ref.3) has reported a prism that can be used instead of the Porro prisms in crossed-Porro type lasers. These prisms, which are simply called compound total internal reflection (TIR) prisms, will be shown to give significant advantages over the use of Porro prisms when used in polarisation coupled laser resonators.

2. DESCRIPTION

The compound TIR prism is shown in figure 1. It consists of four flat surfaces, three of which are inclined at 90° to each other and the fourth inclined at 45° to one of the roof edges formed by the other three sides. A ray entering the surface 'A' at normal incidence will undergo four reflections, each at 45° incidence, before emerging from surface 'A'. Provided the refractive index of the prism exceeds $\sqrt{2}$ each reflection will be total and no energy will be lost. The four reflections are such that the S and P components of the beam are interchanged as the beam traverses the prism (see figure 1). This allows the phase shifts that occurs between S and P components on total internal reflection to cancel, giving no phase shift due to this cause. There is another effect that produces a phase shift and it is the image reversal that occurs when the beam is reflected by the prism. It causes an effective phase shift of 180° in that component of the radiation that is polarised parallel to the y-axis, hence the phase shift produced by the prism is the same as that produced by a half wave plate. A plane polarised beam, entering the prism with its plane of polarisation inclined at an angle θ to the X axis shown in figure 1, will emerge from the prism with its plane of polarisation rotated by 2θ.

A Porro prism operates a little differently from the compound TIR prism in that only two total internal reflections occur and the phase shifts occurring at each reflection add rather than cancel. The total resultant phase shift between S and P components from a Porro prism is given by the following expression

$$\text{phase shift} = \pi + 4\tan^{-1}\{\sqrt{[1 - 2/(n^2)]}\}$$

where n is the refractive index of the Porro prism. The fact that the phase shift is not π or a multiple thereof leads to some performance limitations in crossed-Porro lasers, as will be discussed.

In the laser application, a compound TIR prism is placed at each end of the resonator as shown in figure 2. As in the case of the crossed-Porro laser an in-line or folded configuration can be used. The compound TIR prism at the Pockels cell end of the laser is orientated at 45°(θ) to the pass plane of the polariser so that the reflected beam receives a 90°(2θ) rotation in its plane of polarisation. This rotation leads to the best possible hold-off in the Q-spoiled state, that is, hold-off limited only by the imperfection of polariser and Pockels cell. In the case of a laser using Porro prisms, the Pockels cell must be biassed to achieve the same hold-off. The elimination of the bias requirements when using compound TIR prisms leads to much simpler driving circuits for the Pockels cell and also is likely to allow more reliable operation, since possible electrical leakage problems will be avoided.

The compound TIR prism at the laser rod end of the resonator is used to control the output coupling by rotation about an axis parallel to the laser beam. At an orientation of ϕ, defined in figure 2, the output coupling has an effective reflectivity given by

$$R = \cos^2(2\phi)$$

which can be varied between 0 and 100%. The effective reflectivity is plotted in figure 3 for the compound TIR prism as well as for various Porro prisms of different refractive indices(ref.1). It is obvious that the range of reflectivities is greatest for the compound TIR prism, a feature that could be useful in special cases for example, in very high gain lasers where very low reflectives are desired or where the intracavity power levels are required to be kept as low as possible.

The retro-reflecting properties of the compound TIR prism are the same as those of a Porro prism, hence for the laser to possess insensitivity to mechanical shocks and vibration the insensitive X-axes of the compound TIR prisms must be substantially crossed. It is not possible to have them exactly crossed because this would lead to 100% output coupling, however there is little deterioration in the resonator's insensitivity to mechanical shocks and vibration when the coupling prism is oriented to give a practical output coupling.

There is a further application in which the properties of the compound TIR prism prove useful. In a recent study on high gain Nd:YAG lasers(ref.4) it was found that in a conventional electro-optically Q-switched resonator the maximum output obtainable using a zero order quarter wave plate to provide hold-off was considerably higher than the maximum obtainable using a biassed Pockels cell to provide hold-off. The compound TIR prism produces the same result as a quarter wave plate and 100% mirror combination and its use leads to the following advantages:

(a) there are only two passes through a lossy transmitting surface compared to four with the quarter wave plate/100% mirror system, hence greater efficiency is obtained

(b) there are fewer damage prone dielectric surfaces and

(c) in one plane the sensitivity to angular misalignment is considerably reduced.

3. CONCLUSION

The use of compound TIR prisms in polarisation coupled lasers introduces several advantages over the use of Porro prisms. Foremost are the performance advantages of best possible hold-off without the need to bias the Pockels cell and the capability of extending the range of output coupling. Another advantage is the independence of resonator performance on the refractive index of the prism, a feature that allows the choice of prism material to be made on such grounds as thermal stability, optical quality, absorption coefficient, damage threshold, etc, rather than on refractive index, as in the case of Porro prisms.

In conventional Q-switched Nd:YAG resonators, replacement of the 100% reflecting mirror by the TIR prism gives better hold-off, higher damage threshold and some insensitivity to angular misalignment.

4. ACKNOWLEDGEMENTS

The author wishes to thank Mr D. Rees for many helpful discussions concerning the use of the compound TIR prism in laser resonators. Thanks are also given to Dr R. S. Seymour and Mr M. M. Wolf for their help in evaluating the reflecting properties of the prism.

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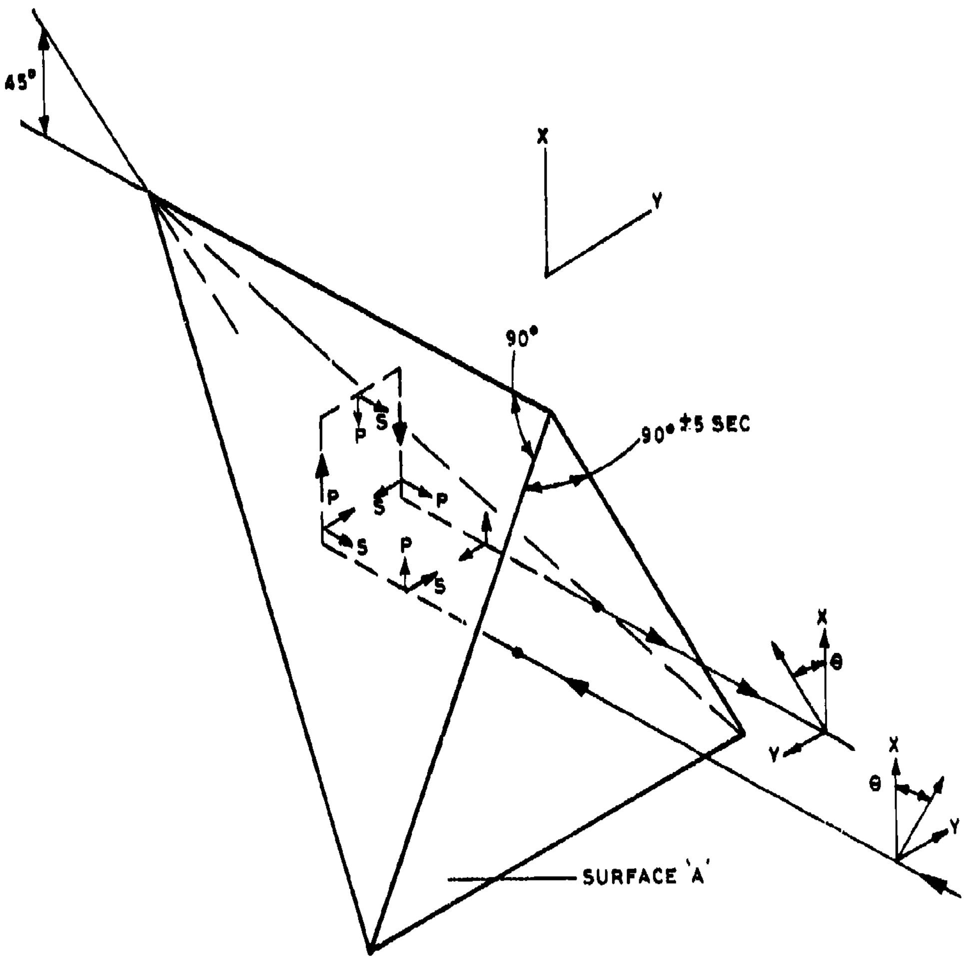

Figure 1. Compound TIR prism

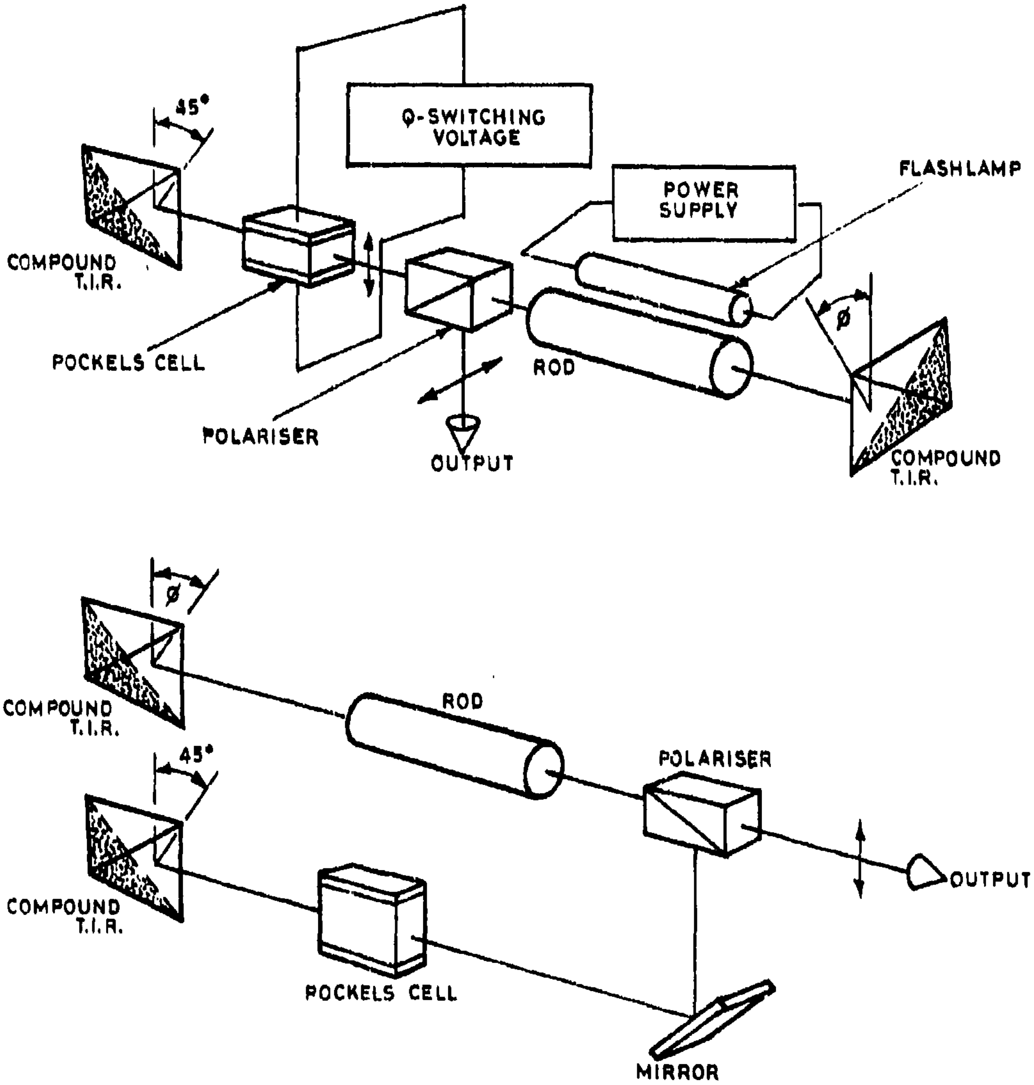

Figure 2. Schematic diagram of in-line (2A) and folded (2B) laser employing compound TIR prism

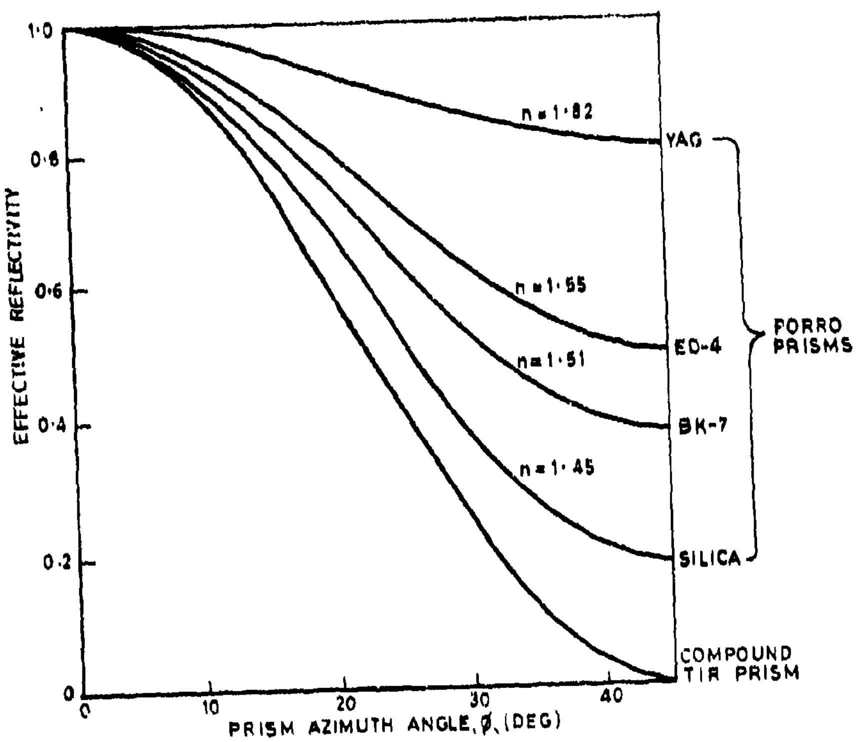

Figure 3. Dependence of effective reflectivity on orientation for various prisms

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