

# **Fabrication of Cheap Optical Transducers (CHOTs) on film carriers for in-situ application and generation of surface acoustic waves**

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**Abstract.** Cheap optical transducers (CHOTs) are patterns on the surface of a component activated by lasers to generate and detect ultrasound. Excited optically, with minimal surface impact, and fully customizable, CHOTs provide a simple alternative to conventional piezoelectric transducers, offering wireless, remote operation. Of particular interest is application of CHOTs for in-situ ultrasonic inspection of hard-to reach and complex-geometry components such as those of aero-engines. A suitable fabrication method has been developed to allow in-situ application of CHOTs onto large size and curved components, as well as those already in service, challenging for current laboratory-based micro-patterning methods. This work describes the fabrication of a transferable g-CHOT for generation of ultrasound. The g-CHOT has been made on an SU8 carrier film using a sacrificial polystyrene layer, allowing the transducer to be transferred from the substrate and subsequently delivered and applied to the surface of the sample in-situ. The functionality of the fabricated transducer is demonstrated by detection of the Surface Acoustic Waves (SAW) generated by the g-CHOT transferred onto glass and aluminium samples.

## **1. Introduction**

Cheap Optical Transducers (CHOTs) are nanometer-height patterns attached to or printed on a component and activated optically using laser light to generate (g-CHOT) and detect (d-CHOT) ultrasound [1]. Using principles of laser ultrasonics [2] they provide a simple alternative to conventional piezoelectric transducers (PZTs) in instances where remote non-contact operation is required. Additionally, used with the endoscopic CHOTs pulser [3], they offer simplified and flexible probe instrumentation when the access path and size considerations restrict the use of other laser ultrasonic techniques [4-6], providing greater efficiency [7]. Demanding applications, such as the in-situ non-destructive testing (NDT) in aerospace industry, frequently require testing of components with surfaces of complex geometry, hard-to-reach components in locations with limited access or in hot, hazardous environments. These conditions are equally challenging for the PZTs due to their contact nature as well as for the spatially-consuming instrumentation of the laser ultrasonic detection methods [6], restricting the use of both techniques.

The endoscopic CHOT system [3] combines the use of CHOTs with the fibre light delivery to enable in-situ ultrasonic testing of the aero-engine components. Its development has been paired with



the upgrade of the CHOT manufacturing methods to satisfy industrial requirements for the in-situ application of the transducers. This paper presents the fabrication method and functionality test results of a transferable g-CHOT, produced on a carrier film to enable transducer transfer to components and in-situ application, previously limited to a laboratory environment. Overcoming the restrictions of the direct sample-patterning methods used previously also allows application of CHOTs onto large and curved components, complementing the endoscopic system.

## 2. CHOTs for in-situ application and testing

The g-CHOT pattern, used for generation of ultrasound, consists of alternating areas of high and low absorption converting incident radiation energy into acoustic waves [1, 8, and 9] via a photo-thermal effect. The g-CHOT design determines the characteristics of the generated ultrasound [8] and the pattern geometry can be configured to produce plane or focused, surface or bulk acoustic waves [9] of desired frequency.

CHOTs could be manufactured by a number of micro-patterning methods. Although such methods (e.g. photolithography, direct material deposition through masks) provide precise feature control and repeatability, they are hard to implement with large size or curved parts due to process complexity or equipment requirements, and they could not be applied to components in-situ. This task could be achieved by alternative methods that offer in-situ fabrication of CHOTs (laser etching or laser induced forward transfer (LIFT)). Another method is the creation of a transferable CHOT, described in this work, which combines the control and repeatability of the laboratory-based fabrication with the flexibility and ease of the in-situ application.

Transferable CHOT is created by producing a CHOT pattern on a carrier film separated from the substrate with a sacrificial layer (figure 1(a)). The sacrificial layer is later dissolved releasing the CHOT carrier (figure 1(b)) and allowing the transducer to be transferred and applied to components when and where it is required.

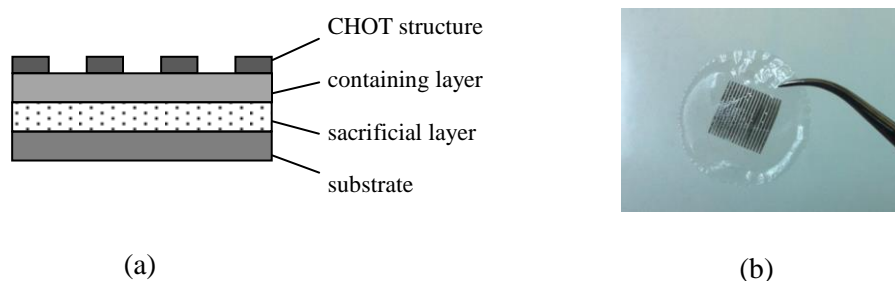


Figure 1. Transferable g-CHOT. (a) Schematic of the fabricated structure, (b) Released g-CHOT on an SU8 carrier.

The use of polystyrene (PS) sacrificial layers is simple, provides fast etching times [10], and has been previously demonstrated [11] for successful release of structures from photoresist SU8. The transferable CHOTs described in this work were produced on SU8 carriers using PS sacrificial layers following similar and adapted procedure. The use of SU8 as a CHOT carrier suits the required application providing film transparency necessary for transducer operation.

In the work presented here, transferable g-CHOTs for generation of 5MHz plane SAWs on aluminium (Al) samples were made of 70nm of Chromium (Cr) with the corresponding spatial period of the pattern  $\sim 720\mu\text{m}$  and the pattern size  $10\times 10\text{mm}$ .

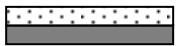
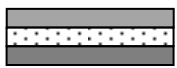
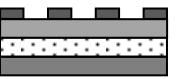
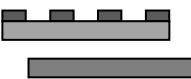
## 3. Method

Precision glass windows from Comar ( $\varnothing 25\text{mm}$ ) were used as substrates. Polystyrene solution was prepared, spin-coated onto the cleaned substrates and baked to create the sacrificial layer. The containing layer for the transducer was then created by spin-coating of SU8 on top of the glass-PS

structure. The resulting structure with SU8 was then pre-baked, exposed to UV and post-baked according to manufacturer's guidelines [12]. The g-CHOT pattern was then produced onto the glass-PS-SU8 structure by direct deposition of 70nm of Chromium in a sputterer through a mask.

The sacrificial layer of polystyrene was finally removed by immersion of the samples in toluene for approximately 5 hours, after which the film containing the transducer was released and dried. Fabrication stages, materials and parameters used are shown in Table 1.

Table 1. Fabrication process of a g-CHOT on an SU8 carrier.

Sacrificial layer PS 100k 10% solution	Containing layer SU8-100	CHOT Cr	Carrier separation Toluene
			
Spin-coat: 30" at 700rpm	Spin-coat: 10" at 500rpm 30" at 2500rpm	Deposit metal in sputterer: 70nm	Immerse structure: 5hrs + agitation
Bake: 1 hr at 100°	Pre-Bake Expose Post-bake Develop		

#### 4. Fabricated transducer

The functionality of the fabricated transducer was demonstrated by detection of the SAWs generated by the transferred g-CHOT under laser illumination (figure 2). The g-CHOT structure, coupled to a glass sample with industrial gel couplant, was activated by illumination from a q-switched Nd:YAG with average power of 450mW at  $\lambda=1.064 \mu\text{m}$  and 1kHz repetition rate. The detection of the generated acoustic waves was performed by a d-CHOT produced directly on the

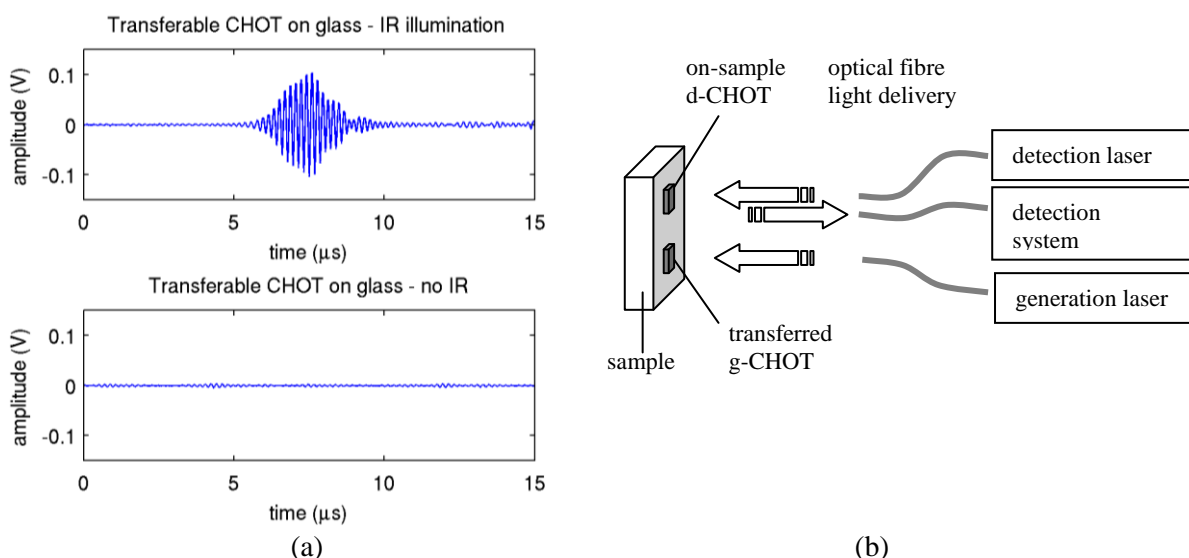


Figure 2. Functionality test. (a) SAWs detected upon laser illumination of the transferred CHOT (top), and the signal recorded in absence of laser illumination (bottom), (b) Experimental setup.

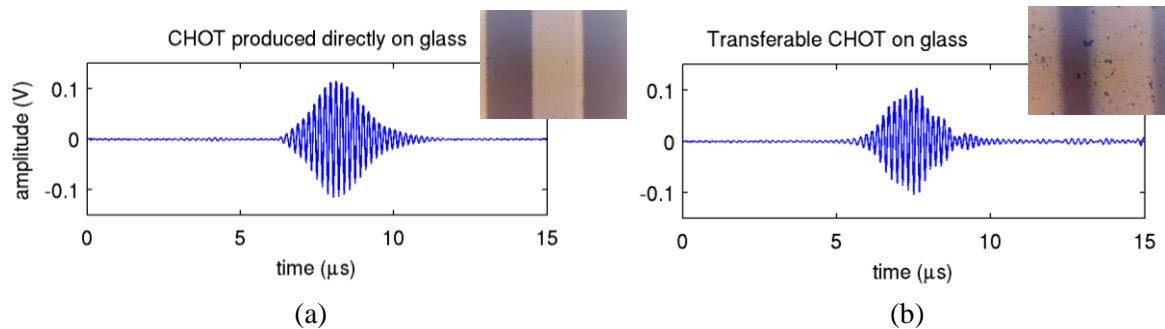


Figure 3. SAWs detected from a g-CHOT produced directly on a sample (a) and from a g-CHOT on a carrier transferred onto the sample (b); microscope images of the corresponding CHOT structures in reflection, with the light areas corresponding to Cr (insets).

sample surface and illuminated by a continuous wave second harmonic Nd:YAG emitting at  $0.532\mu\text{m}$  and providing 120mW power. Signal acquisition was performed using a 5MHz band-pass filter, averaging 1000 waveforms and using 2xZFL500-LN amplifiers from Minicircuits. Figure 3 shows a comparison to the SAWs detected from a g-CHOT produced by direct sample patterning.

The ultrasonic generation by a transferred g-CHOT could result from the ultrasonic source located a) on a carrier, with the g-CHOT absorbing the radiation, and b) on the sample surface with the g-CHOT spatially modulating laser illumination and absorption by the sample [13]. The detection of SAWs shown on the glass samples confirms the g-CHOT as the ultrasonic source due to the absence of absorption by glass.

Further investigation on aluminium samples allows isolation of the two generation mechanisms by reversing the sides with which the transducer is coupled to the sample, and therefore changing the role of the g-CHOT from a transducer to a mask (figure 4). The clear detection of SAWs in the first case (g-CHOT=transducer) and absence in the second (g-CHOT=mask) confirms the preservation of the generation mechanism employed by the g-CHOTs produced by direct sample patterning. A Polytec vibrometer (OVF534) and a 5MHz band-pass filter were used for detection, with the generation setup as described previously.

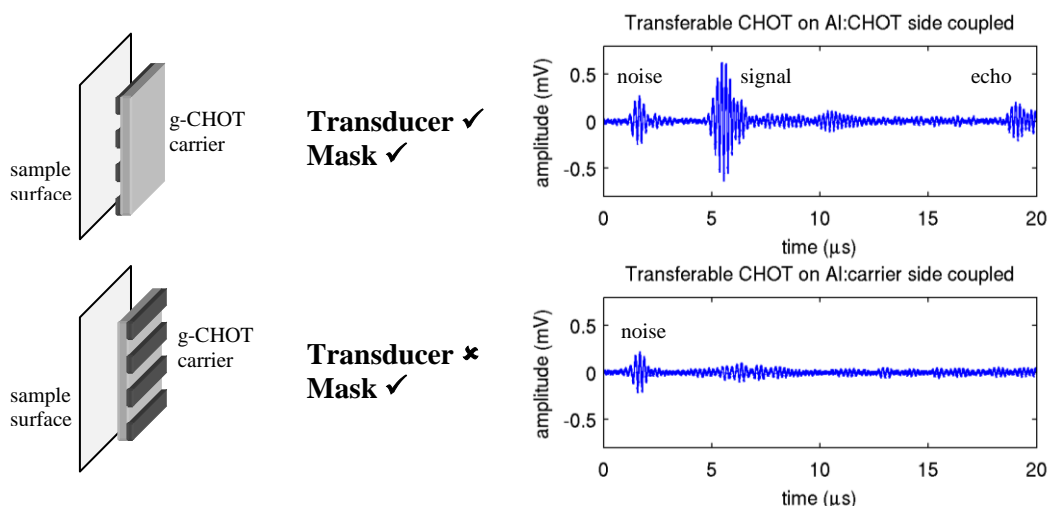


Figure 4. Generation mechanisms demonstrated on Al samples. Top: signal recorded with the patterned surface coupled to the sample, Bottom: signal recorded with the carrier surface coupled to the sample.

## 5. Conclusions and further work

This work presented a fabrication method developed to produce a transferable g-CHOT, Cheap Optical Transducer used for generation of ultrasound, which could be applied in-situ. The developed method allows the sensor to be fabricated on a carrier film in controlled laboratory environment and consequently be transferred and applied to components where and when it is required. This enables CHOTs to be used for testing of large, curved-surface components, as well as providing the means of sensor delivery to the parts already in service, and complementing previously developed endoscopic CHOTs pulser. Functionality of the fabricated transducer was shown on glass and Al samples, with comparative results from the g-CHOTs produced on samples directly.

Increasing the flexibility of the CHOT carrier and developing more permanent means of transducer attachment is currently under investigation, as well as the fabrication of a transferable d-CHOT for detection of SAWs.

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