

Building Integrated Photo-Piezoelectric Cells for Multi-Source Energy Conversion

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ABSTRACT: Established renewable energy technologies such as solar panels and wind turbines utilise only one renewable source for each type and are often bulky, inefficient or noisy. A new generation of 'hybrid' renewable energy technologies is envisaged which will be able to harness power from more than one source (solar, wind, wave) and so will be more efficient and improve the continuity of supply conversion.

The current shortage and high cost of silicon stock has driven research into developing new and efficient thin film solar cells, which require far less expensive material. The overall energy conversion efficiency of solar cells can further be increased by incorporating into new practical devices that make use of other renewable energy sources.

Laboratory testing has been carried out for polarised PVDF films. A piezo-stack for improved power output has been built and tested into a new 'louvre' device suitable for building integration. The test was carried out for a range of wind speeds and tilt angles in order to maximise the power output.

Computer modelling for theoretical analysis has also been carried out to optimise the geometry, and predict the behaviour of the composite material under a range of conditions (solar insolation, wind speeds, tilt angles).

In the case of solar/wind conversion, methods for optimum building integration of the material are proposed to take full advantage of solar radiation and wind flows around the building.

Keywords: composite material, photo-piezoelectric, PVDF film, building integration.

1. INTRODUCTION

These days, global warming is being addressed worldwide and taking such an important relevance over the awareness of people, governments, and scientific community. In this respect sustainable energy technologies are in demand which make use of free energy from the environment and transform it into useful electricity.

The built environment offers a good opportunity to integrate systems that can harness free energy from the environment. Buildings should be energy producers over the course of the year rather than consumers. This can be reached by means of reduced energy consumption, optimum building design/orientation, energy efficiency and energy generation technology.

1.1 Piezoelectric Films

Piezoelectric films have been used so far for sensing applications, but this material offers a great potential for power harnessing that could be integrated into the built environment. Piezoelectric films can generate either low or very high voltages which can be used for high and low charge applications.

Low charge applications include sensing the nV spectral density range, such as strain detectors for counterfeit coins, turbulence occurring within liquid or gas flowing inside a pipe, and sensing vital signs such as pulse rate and respiration, detection of acceleration, vehicle motion, anti-theft vibration alarms, etc.

Research has been carried out to harness power from the human body [1] [2]. High density power applications include chargers of electronic devices such as mp3 players, mobile phones, PDA's, etc.

Detection of high frequency (40 kHz to 200 kHz) is used for applications such as conference room whiteboards, and personal devices for handwriting or graphics input.

The film can also be used for detection of thermal transient signals and actuator for audio systems and ultrasonic transducers.

From the work of Gonzalez, et al. [3] it is shown that activities such as walking or breathing would be enough to power wearable units with communication systems like GSM or Bluetooth incorporating computing, communication and audio functions.

Piezoelectric stacks have proven to be able to generate more power than what a single layer can produce. Kymissis [2] built a 16 layer stack of 28 micron epoxy-bonded stave made from laminate of PVDF foil. It worked into the '3-1' longitudinal mode of piezoelectric coupling in PVDF. It was embedded into a shoe sole and tested at a normal walking pace. It was connected in parallel in order to lower the impedance of the material (to avoid cancellation of charges). This system produced voltages of

± 60 volts under a $250\text{ K}\Omega$ and produced peak power outputs close to 20 mW.

1.2 Amorphous Thin-Film Silicon Solar Cells

Thin semiconductor films instead of high-purity bulk materials are used for new development of solar cells. The current crystalline silicon shortage [4] has driven research into making more efficient and price competitive solar cells. Because of the shortage of solar grade silicon, other techniques are being explored; these include the use of solar concentrators, and techniques to use less silicon, producing thinner Si wafers (reduction from 270 to 180 μm) with further reductions due to enhancement in light trapping, surface texturization and advanced coatings.

Due to the inefficiency of sawing the cylindrical Czochralski boules, other methods are being explored which include edge defining film-fed growth, string ribbon and silicon sheet from powder.

This situation will assure the future of silicon feedstock. There has been a steady cost reduction in silicon modules over time. It is estimated that by 2013 the PV generated electricity will have similar costs to conventional sources of energy [4].

Thin film solar cell technologies are a good alternative to alleviate the need for large amounts of Si. Research on triple junction thin film silicon solar cells has proven that they have enhanced performance [5] under low-light conditions, non-ideal orientation, or high temperature of the modules (BIPV systems). With efficiency of 7.0-7.5%, each cell takes advantage of the red, green/yellow and blue light. This spectrum capability is a key of its higher efficiency especially at low irradiation levels and under diffuse light. These types of cells are being produced already in a roll-to-roll vacuum deposition process, employing only a fraction of material and energy of the production of standard crystalline silicon solar cells.

As they are flexible and lightweight, they can be bonded to roofing materials, ranging from metals to polymeric membranes. This technology makes a suitable type for the combined PV + PE effect.

Low levels of irradiation, under 300 W/m² diminishes the efficiency of c-Si modules and thin film technology. Triple junction solar cells have proven good efficiency with levels as low as 50 W/m². This is important to consider in Northern and Central European climates where low light conditions and diffuse light prevail.

Thin film solar cells are expected to play a major role in the photovoltaic market [6].

2. EXPERIMENTAL SETUP

A piezo-stack made out of polarised PVDF film was made. Five sheets of 110 µm thick each, measuring 20.3 x 14 cm, were connected in parallel in order to maximise the power output.

The samples of piezoelectric material were tested under three different wind velocities. Fig. 1 shows the films under testing.

The horizontal wind speeds used were: 3.0 m/s (Velocity 1), 4.5 m/s (Velocity 2) and 5.4 m/s (Velocity 3). They were chosen based on the average wind velocities found in the East-Midlands area of the UK which is between 4 and 7 m/s.

The air velocity was generated by a controlled 0.9 kW air blower. The recordings were taken with a PCI-DAS1000 computer board and a 16 channel connector box.

The resistance of the circuit corresponds to 50Ω which comes from the internal circuit of the connector box. The piezo films were attached via a supporting structure as in a building integrated louvre device, which allows the tilt angles to be controlled (Figure 1). The tested angles are 9, 15, 30, 45 and 60° from the horizon as they are suitable for shading devices. The stress and strain that produced a voltage output over the length of the stack were recorded.

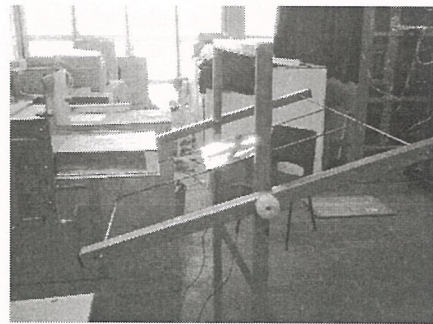


Figure 1: 550µm piezo-stack in supporting structure.

3. RESULTS AND DISCUSSION

The piezo film stack was tested under the three different wind velocities and five different angles. The peak and average RMS power and voltage outputs are summarised on Table I.

The best results were achieved when the stack was at 9° angle from the horizon and the horizontal air speed was 5.4 m/s. At this velocity the vibration across the stack caused the greater mechanical stress, thus the tension and compression forces caused the higher voltage outputs.

The output power was calculated using the equation $P=V^2/R$. A 50Ω resistance was considered on the circuit.

Table I: Summary of peak and average power and voltage outputs for piezo-stack.

	Voltage (V)	Power (W)
	Average	Average
9 deg		
3 m / s	1.10 E + 00	4.02 E - 02
4.5 m / s	8.20 E + 00	1.38 E + 00
5.4 m / s	8.30 E + 00	1.38 E + 00
15 deg		
3 m / s	4.00 E - 01	4.98 E - 03
4.5 m / s	2.10 E + 00	9.80 E - 02
5.4 m / s	2.63 E + 00	1.52 E - 01
30 deg		
3 m / s	6.30 E - 01	1.04 E - 02
4.5 m / s	7.60 E - 01	2.02 E - 02
5.4 m / s	1.28 E + 00	6.13 E - 02
45 deg		
3 m / s	1.96 E + 00	8.75 E - 02
4.5 m / s	7.50 E - 01	2.23 E - 02
5.4 m / s	8.00 E - 01	2.08 E - 02
60 deg		
3 m / s	6.00 E - 01	1.04 E - 02
4.5 m / s	5.80 E - 01	1.12 E - 02
5.4 m / s	1.61 E + 00	5.79 E - 02

The highest peak power value was 2.0 W for the PVDF stack at 5.4 m/s, while the highest average value was 1.38 W at the same velocity (Figure 2).

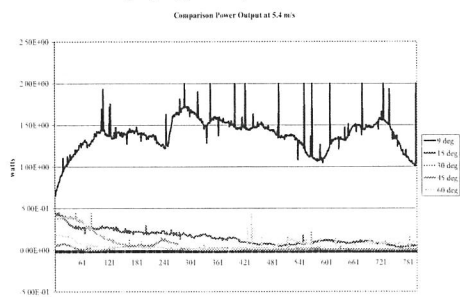


Figure 2: Piezo film stack reached 2.0 W peak power.

A further test was carried out for the stack using a 12 K Ω resistance via a decade resistance box. This value was used in order to match the impedance of the film and therefore maximise the power output.

It can be seen in Figure 3 that the trend is confirmed with this new set of data. The best results correspond for 9 degrees tilt working at 4.5 m/s giving 0.27 mW average power. Compared to the previous tests, velocity 2 showed slightly better results than velocity 3.

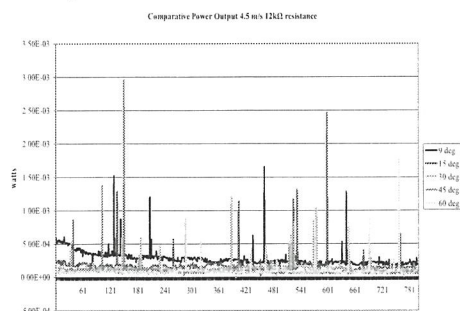


Figure 3: Piezo film stack reached 0.27 mW peak power.

Figure 4 shows the effect of tilt angle on the power output at velocity 3. It can be seen that the lower angles correspond higher power output for the effect of the wind onto the PE.

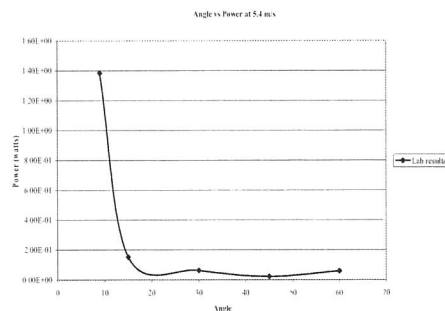


Figure 4: Power vs tilt angle at velocity 3

Figure 5 shows the effect of wind speed on the power output (at 9 degrees). It shows an average value of over 1.5 W of power for a wind speed of 5.5 m/s. It is important to notice that the 1 W line is reached with wind speeds of 4.0 m/s and above.

Comparing power outputs of PV and PE, a typical monocrystalline module with 15% efficiency produces 1.5 W on a 10 x 10 cm surface under standard test conditions [7], while the 5 layer piezo-stack for the same area would produce 0.48 W at a wind speed of 5.5 m/s.

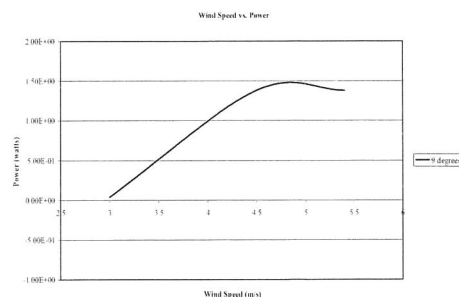


Figure 5: Wind speed vs power at 9 degrees tilt.

4. BUILDING INTEGRATION STRATEGIES

When considering building integration for a PV + PE system, the optimum orientation for both solar and wind should be considered. A compromise will need to

be done between the output from best solar vs. best wind.

A system could be installed in any surface that benefits from sun. It can be integrated into roofs (supporting devices) and walls (louvers, shading devices).

As an example let's consider the Golf 2001 building in Santiago, Chile by the architect Borja Huidobro (Figure 6). It has an east facing façade, receiving solar radiation in the morning. The building considers integrating shading elements via louvers to protect from sunshine. If such systems could also benefit from full sunshine (true north or south) and wind effects the energy generation would be greatly improved.



Figure 6: Example of vertical (façade) integration.

It can also be integrated in a horizontal way, via shading devices (canopies). Figure 7 shows this way of integration on a housing project.



Figure 7: Example of horizontal (canopy) integration.

In order to predict the behaviour of the composite material under a range of conditions (solar insolation, wind speeds and tilt angles), two locations with very different solar radiation levels were chosen - London (51.4°N, 0.0°E) and Mexico City (19.2°N, 99.1°W) to compare the performance of the 5 layered piezo-stack composite material. Table II shows the contribution in W/m² of the combined effect of solar and wind. The PV output is considered with 7% efficiency of the cell and an orientation of 0° azimuth, the varying angles of 9, 15, 30, 45 and 60° and wind speed of 5.4 m/s.

Table II: Comparison of combined output of PV + PE

Combined effect PV + PE at 5.4 m/s			
Mexico City			
Tilt (angle)	Solar PV (W/m ²)	Piezofilm PE (W/m ²)	PV + PE (W/m ²)
9	15.18	48.55	63.73
15	15.32	5.34	20.66
30	15.15	2.15	17.3
45	14.22	0.73	14.95
60	12.61	2.03	14.64
London			
Tilt (angle)	Solar PV (W/m ²)	Piezofilm PE (W/m ²)	PV + PE (W/m ²)
9	8.07	48.55	56.62
15	8.27	5.34	13.61
30	8.52	2.15	10.67
45	8.38	0.73	9.11
60	7.87	2.03	9.9